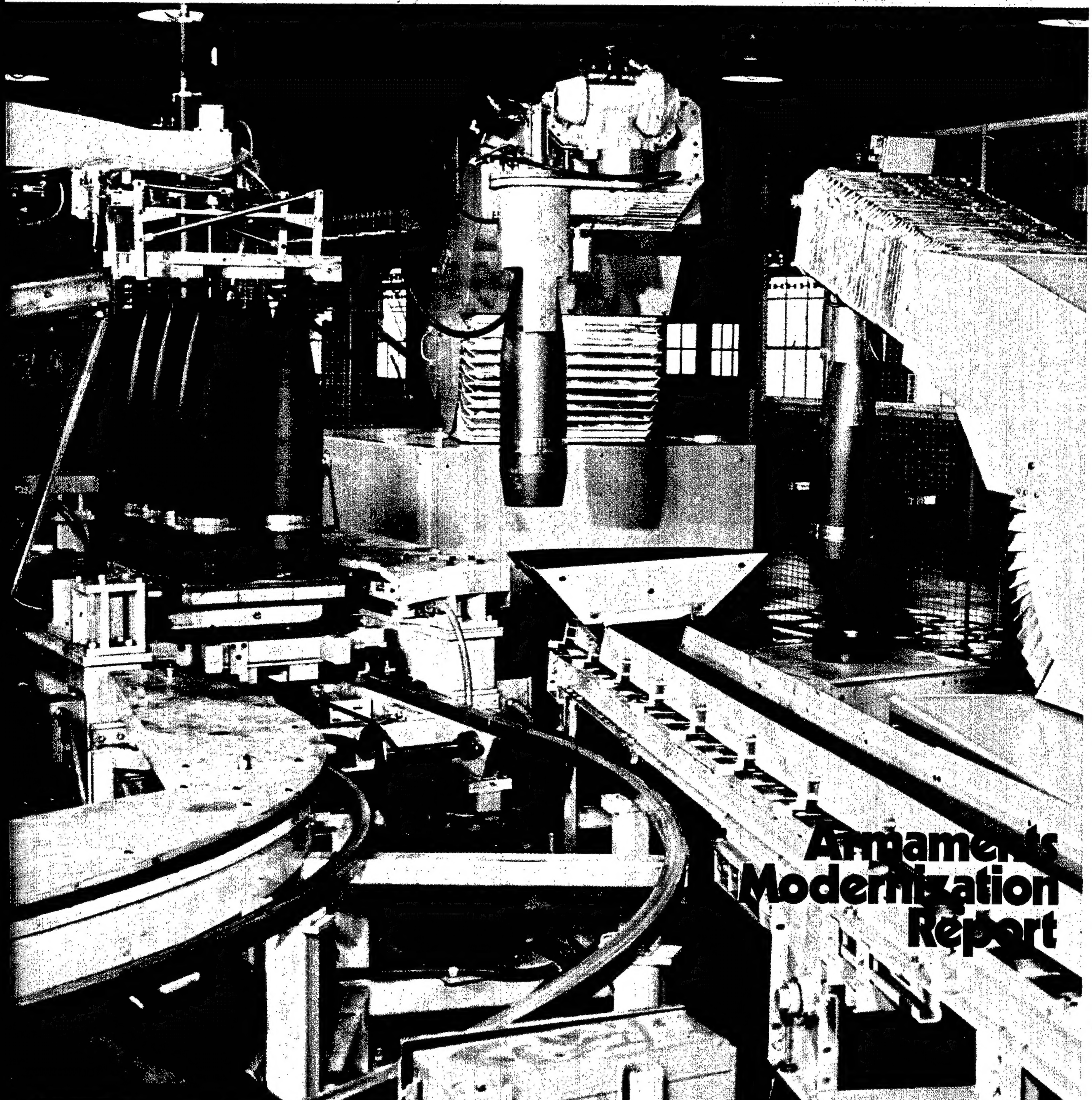
US Army

ManTech Journal

An Evolution In The Making

Volume 1/Number 1/Fall 1976



Armaments Modernization Report

THE MANTECH JOURNAL is published quarterly for the U.S. Army by the Army Materials and Mechanics Research Center, Arsenal Street, Watertown, Massachusetts 02172, through the Metals and Ceramics Information Center, Battelle, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

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Contents

ABOUT THE COVER:
Robots in action are typical of the systems going into operation in the Army's ammunition plants all over the country; they are being tied into computerized machining and assembly centers as in this scene from the Iowa Army Ammunition Plant in Middletown, Iowa. Eight-inch projectiles, six per pallet, move into position from the left, and the pallet top is removed. The robot in the center removes a projectile from the pallet and transfers it to the nest in front of the robot on the right. After setting the projectile down, the lifting plug is removed from its nose and is dropped into the hopper on the conveyor (in center of photo) as the robot moves back to pick up another projectile. When the pallet is empty, a full one moves into position automatically. The robot on the right picks up the projectile from the nest and places it into one of the holes in the 15-hole process cart (between the robot and wire mesh guard). When the process cart is full, the full one is automatically indexed out and an empty one in. The system rate is six projectiles per minute.

Comments by the Editor

Essential to the management of the Army ManTech program is exchange of timely information on the content and progress of the development projects; publication of the U.S. Army ManTech Journal provides a means for such communication. The Journal will provide both in-depth reports on major developments in the program and summaries of the present status of principal projects.

The Journal will be published quarterly, with Volume I being devoted solely to the Army. However, future volumes will highlight various individual Army Commands, with input both from other military organizations and segments of the Government and industry.

The main purpose for having the ManTech Journal is:

- To provide a means for coordination of the programs being conducted throughout the military services
- To encourage early implementation of the results of the programs both by Government and military oriented industry
- To make known current and potential benefits of the Army ManTech Program and facilitate transfer of these developments to nondefense oriented industry.

The Special Report of the past summer to the Congress by the Comptroller General of the United States, "Manufacturing Technology—A Changing Challenge to Improved Productivity", points up the fact that certain industries in the United States have fallen behind their counterparts in some foreign countries technologically. There are clearly understood reasons for this occurrence and a concerted effort on a national scale is needed to correct the deficiencies, as pointed out by the GAO report. Since most military production fits into this category and since costs simultaneously have skyrocketed for most military items, the MM&T program of the Army has special

DR. JOHN J. BURKE is Associate Director for Plans and Programs at the U.S. Army Materials and Mechanics Research Center, Watertown, Massachusetts, and has served in a variety of positions over the past twenty years at AMMRC. In addition to his extensive technical experience in research and engineering, he is noted for his expertise in technical forecasting and long-range planning. Immediately prior to his appointment as Associate Director Dr. Burke was Planning Director, and prior to this, he was Chief of the Processing Research Division, directing a variety of efforts designed to improve the processing of metals, ceramics, polymers, and composites. Dr. Burke is the inventor of the SPIDERCHART (Systematic Planning for the Integration and Direction of Engineering and Research) management concept and has been guest lecturer on the SPIDERCHART concept at Syracuse University, Georgia Institute of Technology, Tufts University, and Northeastern University; and, also, with industrial and governmental organizations. The SPIDERCHART today is widely used by the Military and by industrial concerns to manage and control complex interrelated operations, permitting decisions to be made in a step-by-step sequence with follow-on action. A member of American Men of Science and Sigma XI and numerous other scientific groups, Dr. Burke holds a B.S. Degree in Physics and an M.S. in Geophysics from Boston College, and an Engineering Degree, an M.S. in Metallurgy, and a Sc.D. in Metallurgy and Materials Sciences from M.I.T. He has authored numerous Government reports and is coauthor of the first book on titanium, "Titanium in Industry", published by D. Van Nostrand Company. In addition, he is coeditor of fifteen technical books.

significance nationally. Much of the applied technology being implemented right now in the Army's program will also be directly applicable to many nonmilitary industries.

A point of interest evident in the choice of articles for this first issue is that sometimes highly cost-effective procedures are not necessarily strictly manufacturing processes. That is, sometimes attention to details of ancillary production problems, such as water supply, safety procedures, or quality control, can beget just as many savings as production of more units of an item faster with less material and labor. There are many articles coming up in future issues of the ManTech Journal that will deal directly with manufacturing processes and will outline some dramatic achievements in purely production related subjects, but there will also be some of the more "management" oriented articles which will report vast savings from better management techniques.

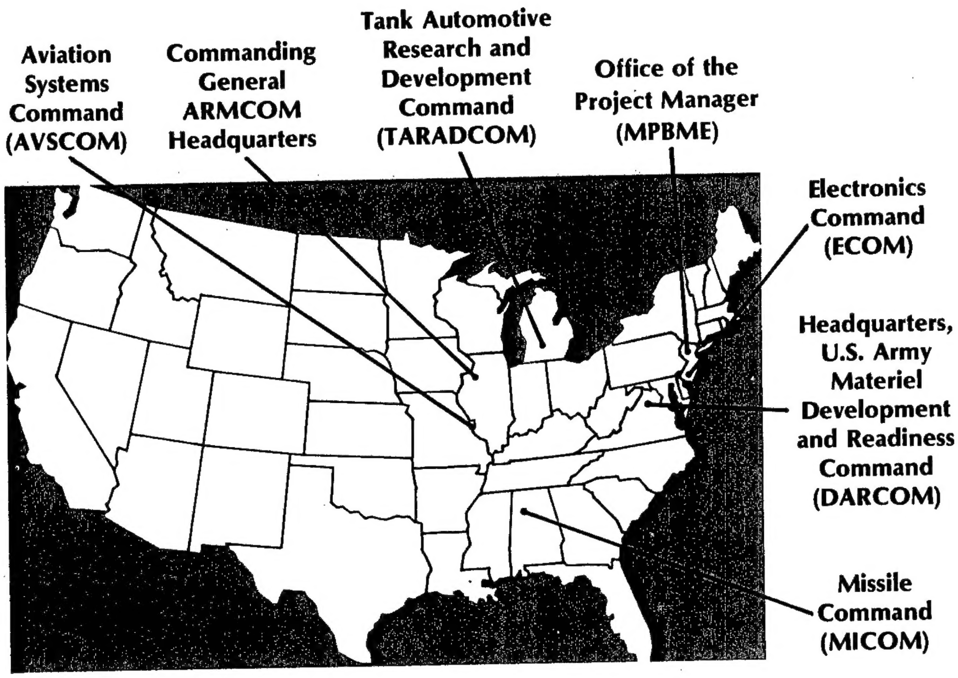
Spearheading this first issue is the U.S. Army Munitions Production Base Modernization and Expansion Program. Overview articles by commanders of the other Army commands are also featured, along with a comprehensive SPIDERCHART showing the detailed organization of the Munitions PBME Program. Brief status reports of especially significant projects currently being conducted are also presented.

The general format used in future issues will include

- A feature article on significant developments in manufacturing technology
- An overview article on the featured command
- Several articles on demonstrated accomplishments of the command
- A SPIDERCHART reflecting the featured command's activities
- Brief status reports on important current projects
- Timely reports from other commands of the Army
- Reports of recent and future meetings.

All in all, the ManTech Journal offers something new and different—in fact, unique in the field of manufacturing technology because of its impact on the nation's military posture and the national economy.

DARCOM Commands Featured in This Issue of the ManTech Journal



Overview of U.S. Army ManTech Program

Manufacturing Technology Important to Materiel Acquisition

General John R. Deane, Jr.
Commanding General
Materiel Development and Readiness Command

Developing, buying, and then maintaining Army materiel becomes more challenging each year as individual systems become more sophisticated and more costly. During the next decade, billions of dollars will be spent on the new systems necessary to maintain an adequate defense. If the Army is to accomplish its national defense mission, ways must be found to overcome the skyrocketing cost of weapon system acquisition. One way to do this is to attack the high cost of production.

The Army cannot do this alone. We must instead utilize the "smarts" of the entire industrial community. We must build and maintain an adequate industrial capacity that is responsive to the nation's needs both in peace and in time of conflict. We must continually search for new and better ways to manufacture products at lower costs.

Deputy Secretary of Defense William P. Clements, Jr., has stated that he is convinced that, by increasing the application of state-of-the-art manufacturing techniques and by developing new or improved manufacturing technology, we can substantially reduce production costs. I could not

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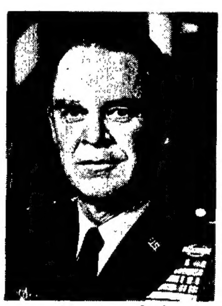

GENERAL JOHN R. DEANE, JR., assumed command of the Army Materiel Command in February 1975 after previous responsibilities in research and development as Deputy Chief of Staff for Research, Development, and Acquisition and Chief of Research, Development, and Acquisition, capping a long and remarkable career that began almost 40 years ago as an infantry enlistee. Later a graduate of West Point, he advanced during WW II to battalion commander at the end of that conflict. He served as Commander of the 82nd Airborne Division and earlier the 173rd Airborne Brigade in Vietnam, and commanded field units periodically for 30 years. He attended many Army schools, including the Command and General Staff College, National War College, Armed Forces Staff College, and Intelligence School, in addition to earning an M.B.A. at George Washington University and completing an Advanced Management Program at Harvard. His career has been marked by distinguished service in the field, in military intelligence and planning, military finance, high level administration, and research and development. Both aviator and infantryman, General Deane holds many service medals, including the Purple Heart.

Manufacturing Technology Management Receives a New Look

LTG George Sammet, Jr.
Deputy Commanding General for
Materiel Development, DARCOM

General Deane, in his introduction to this first issue of the ManTech Journal, makes clear the importance of exploiting manufacturing technology in the production of military hardware. It is unlikely that anyone involved in the materiel acquisition process would argue that point. This should be evidenced by the fact that the Army has already "gotten with the program" in manufacturing technology.

The Army—in particular, the Materiel Development and Readiness Command—is by far the largest investor in manufacturing technology among the military services. As General Deane mentions, over $65 million of Army money is directed annually to improving manufacturing methods and technology, and we intend to double that figure over the next several years.

Obviously, since one of the primary obstacles to success in materiel acquisition today is economy, we could not think of increasing our expenditure on manufacturing technology without a sustantial return on that investment. Experience with the manufacturing technology program has given us just that assurance.

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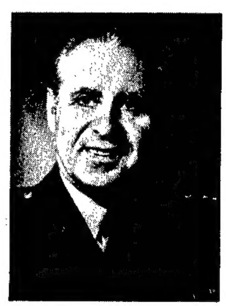


LT. GENERAL GEORGE SAMMET, JR., assumed his present duties as Deputy Commanding General for Materiel Development in October 1975. During his tour of duty with the Office, Chief of Research and Development General Sammet held positions in the International Division, Plans and Programs Division, and Combat Materiel Division, eventually becoming the Deputy Director of Developments. While serving as a member of the Army Reorganization Plan Team, he helped plan for and establish the U.S. Army Limited War Laboratory. General Sammet left OCRD to become Commanding Officer of the Fourth U.S. Army Missile Command in Korea, after which he returned to OCRD as the Deputy Director of Missiles and Space and later as Executive Officer. In September 1967 he became Deputy Director of Development, Army Materiel Command. He has served as Senior Advisor, First ROK Army and Commander, Korea, after which he was again assigned to OCRD as Director of Plans and Programs. In November 1970 he became Deputy Chief of Research and Development. General Sammet returned to AMC and was assigned as Deputy Commanding General for Material Acquisition. General Sammet has attended the Artillery Advanced Officers' Course, the Command and General Staff College, the Armed Forces Staff College, and the National War College.

Manufacturing Technology Important to Materiel Acquisition (cont.)

agree more. It is for this reason that the U.S. Army has developed such an ambitious program in manufacturing technology.

Over sixty-five million dollars is invested each year by the Army Materiel Development and Readiness Command (DARCOM) to develop new manufacturing methods and processing techniques—and we intend to double this investment during the coming years.

The payoffs have been many, and many more are on the way. For example, manufacturing technique studies at the missile conference of last September have already resulted in $2.5 million in contracts for improved manufacturing technology, with potential savings to the Government of over $50 million. But even the best developments and latest techniques are of little value unless they are put to use by the manufacturing community. Both information and incentives must be provided. The purpose of this journal is to share with American industry the latest developments from our investment in manufacturing technology. It will serve as a medium of exchange and, hopefully, as a stimulus to our industrial base.

The importance of manufacturing technology in the materiel acquisition process cannot be overstated, and although the Army has made a strong commitment to DOD on this program, success depends upon every member of the Government/industry team. Active participation by all members will assure us of meeting our materiel acquisition goals and maintaining a strong national defense.

Manufacturing Technology Management Receives a New Look (cont.)

Having said that, let's look for a moment at what we at DARCOM are doing to help give manufacturing technology the visibility and influence it deserves.

As part of the recent reorganization of DARCOM, an Office of Manufacturing Technology was established within the headquarters. The basic mission of this office is to ensure that new or improved manufacturing processes, techniques, materials, and equipment are fully exploited in the production, modification, and overhaul of Army materiel. This will be accomplished by closely examining all end-item programs to see that the latest and most economical methods of production are used at each stage of the acquisition process, including producibility engineering planning, production engineering, value engineering, and evaluation.

Since the Office of Manufacturing Technology reflects the corporate policymaking organization of DARCOM headquarters, two separate organizations have been tasked to provide support for day-to-day management of the program.

The Army Materials and Mechanics Research Center (AMMRC) at Watertown, Massachusetts, will assist in the planning and technology assessments of the manufacturing technology program, as well as in helping to ensure full implementation of the results. The Industrial Base Engineering Activity (IBEA) at Rock Island, Illinois (formerly PEQUA), will participate, as they have for many years, by reviewing and critiquing the ongoing effort.

Earlier, I mentioned the success we have realized in the manufacturing technology program so far. An example of that success is the Missile Manufacturing Technology Conference held last year. This conference gave industry and the DOD the opportunity to reexamine the investment policy in missile manufacturing technology. The net result was an immediate increase in FY 76 of $2.5 million in high-priority projects which had been recommended by the several industrial panels. The most recent conference—studying tracked combat vehicles—was held at Dearborn, Michigan, several weeks ago and is now undergoing evaluation. Additional studies currently in the planning stage include technology assessments of electronic systems, metal chip removal processes, and aircraft systems. A thorough analysis will be made of each of our commodity areas during the next several years. Certain technologies that surface as problems common to several areas will be given immediate attention.

Billions of dollars will be spent during the next decade on materiel acquisition alone, not to mention the additional billions to be spent on maintenance, repair, and overhaul. If we can achieve even a modest—say sixfold—return on that investment, a manufacturing technology expenditure of $150 million would yield a savings of almost $1 billion. The initial investments resulting from the missile conference are expected to produce twelve-fold returns on investment. Since we anticipate an annual manufacturing technology investment of $120 million plus, the potential for savings is enormous.

But the Army depends on industry for success in the manufacturing technology program. The savings I've projected here cannot be realized without total industry involvement and cooperation. The ManTech Journal, the first issue of which you now hold in your hands, as well as brief newsletters that we will publish more frequently, are our attempts to spread the word on manufacturing technology advances throughout the manufacturing community. Timely use of this information can only result in a more efficient acquisition process and a stronger national defense.

Overview of An Army Command ManTech Program

Major General Robert J. Malley
Project Manager
Munitions Production Base Modernization and Expansion
and
Major General Bennett L. Lewis
Commander of U.S. Army Armament Command

Our national productivity must be improved if we are to compete with other industrial nations of the world. This is important to both international trade and our national defense. We have found manufacturing technology to be the key to industrial productivity, but its value doesn't stop there. It also provides superior product quality, conservation of raw materials, a cleaner and safer environment, and more economical products for defense and commercial use.

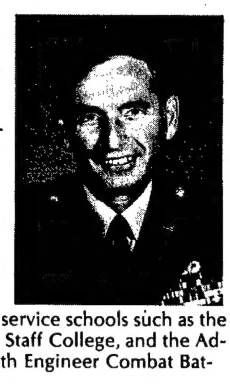
Manufacturing technology won't just happen for you. You have to make it happen. It must be carefully planned, skillfully managed, and wisely implemented. Communications are an important factor in the implementation process and we commend the editors of ManTech Journal for taking on a portion of this awesome and important responsibility.

Utilization of modern manufacturing technology is a prerequisite to the 7 billion dollar munitions production facilities (production base) modernization and expansion program, and in our judgment is a prerequisite to the establishment of every line for production of defense materiel. If one is to achieve reasonable productivity, quality, and economy goals, manufacturing technology for a new factory must be as sophisticated and challenging as the most exotic state-of-the-art weapons system.

And, like its weapons systems' counterpart, it requires a properly time-phased, adequately funded, and orderly systems approach to be successful. We have already invested over 230 million dollars in manufacturing technology for the munitions facilities modernization and expansion program and expect to invest an additional 200 million dollars before all the processes are available to

MAJOR GENERAL ROBERT J. MALLEY brings experience as a teacher, engineer, combat commander, logistician, and large project manager to his command as Project Officer for the Munitions Production Base Modernization and Expansion Program. He previously was Chief, Systems Program Coordinating Committee, Office of the Vice Chief of Staff of the Army. A graduate of West Point, Gen. Malley later taught physics at the Academy. He holds a Masters degree in Civil Engineering from the University of Minnesota and also has completed advanced instruction at the Army Command and General Staff College and the Army War College.
General Malley has served as logistics officer with SHAPE Headquarters, and has commanded an engineer battalion of the 1st Air Cavalry Division and the Task Force Americal of the 23rd Infantry Division in Vietnam. His Pentagon duties include Assistant Chief for Force Development and Plans and Programs Directorate. He also has served as Chief, Logistics Advisory Division, Headquarters, USMACV.

Editor's note: General Malley was transferred to a new position effective October 1 . He is now Director of Combat Support Systems, Office of the Deputy Chief of Staff for Research, Development, and Acquisition in Washington, D.C.



A native of Boston, Massachusetts, MAJOR GENERAL BENNETT L. LEWIS has over 25 years of active commissioned service. He is presently Commanding General, U.S. Army Armament Command, located at Rock Island Arsenal, Illinois. His previous assignment was Special Assistant to the Commanding General, United States Army Materiel Command. General Lewis also commanded the Army's Mobility Equipment Research and Development Center and served as Director of Research, Development, and Engineering for the Army Mobility Equipment Command. A graduate in 1950 of West Point, General Lewis since earned his Master's in Civil Engineering at Harvard, in addition to attending service schools such as the U.S. Army War College, Command and General Staff College, and the Advanced Engineer School. He commanded the 14th Engineer Combat Battalion in Vietnam in 1968.

complete our 7 billion dollar capital investment program. The development of adequate manufacturing technology will require over a decade of intensive effort and as much as a five-year lead time for individual facilities.

Close-Knit Work Required

The management and execution of a manufacturing technology program and the construction of modern production facilities require a close working relationship among the developer of the ammunition, the developer of manufacturing technology, and facilities designers and users of the completed production facilities. We have that kind of a close-knit relationship between the Project Manager for Munitions Production Base Modernization and Expansion and the U.S. Army Armament Command (ARMCOM).

ARMCOM, with the assistance of contractors, develops the munitions, develops most of the manufacturing technology processes and equipment, and participates in the construction of the facilities. Subsequently, it becomes the user of those facilities. The Project Manager's Office is responsible for the planning and execution of manufacturing technology, for the design of the facilities including the process, equipment, and construction, and for the subsequent acquisition of the entire facility.

In accomplishing that mission, it pulls together the resources of ARMCOM, production contractors of ARMCOM, the Corps of Engineers, and private industry at large. It assumes the responsibility for the proper selection of technology and for the choice of detailed designs going into production facilities.

Necessary Facility Characteristics

These facilities, of course, must be available when they are required by the Armament Command; must have sufficient capacity to satisfy both current and mobilization requirements; must provide the anticipated economy of operation; and must be properly located geographically to interface with the rest of the ARMCOM industrial complex. Explanation of this relationship is simplified through the choice of four words in assigning the responsibility for each. The four words are "what", "when", "where", and "how".

The Armament Command determines "what" it needs on the basis of current and mobilization requirements and "where" it wants a facility on the basis of the interrelationship with other facilities within the ARMCOM industrial complex of government-owned, contractor-operated plants and the production equipment packages in private plants. The "when" is determined jointly on the basis of urgency of need, availability of manufacturing technology, and detailed production line and construction designs. The "how"—including the selection of the process and design of the production facility (process, equipment, and construction)—is the overall management responsibility of the Project Manager's Office; ARMCOM has engineering responsibility for the development of manufacturing technology and detailed design for processes and equipment. The Corps of Engineers has similar responsibility for detailed design of the construction portion of the production facility. This simple formula is easily understood and it works.

Mission Remains Unchanged

The reorganization of ARMCOM into U.S. Army Armament Research and Development Command (ARRADCOM) and U.S. Army Armament Readiness Command (ARRCOM) will change only slightly the "what", "when", "where", and "how" formula. Most of the current engineering responsibilities of ARMCOM will be assumed by ARRADCOM. The mission of the Project Manager's Office remains unchanged in the reorganization.

The editors of ManTech Journal have our best wishes for success and our pledge of support for the Journal with quality manufacturing technology articles on a timely basis.

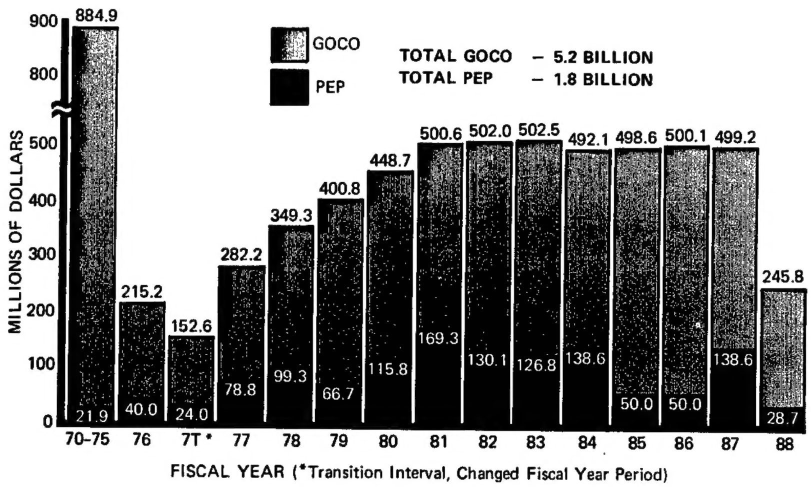


FIGURE 1

Modernizing the Ammunition Production Base

by Charles Bing-Dons
Public Affairs Officer, Office of the Project Manager Munitions Production Base Modernization and Expansion

Subject to Congressional approval, the Army will spend $282 million in FY77 to modernize its obsolete and worn-out ammunition production facilities. The Army's Project Manager for Munitions Production Base Modernization and Expansion—the office which developed the master modernization plan and runs the program—has already received approval to construct facilities and procure equipment costing in excess of one billion dollars. These huge amounts spent in the **past six years** are but a small part of the seven billion dollars (Figure 1) which the Dover, New Jersey, office forecasts. At the end of its twenty year planned effort, the Army will have an up-to-date production base and, as a spin-off, a **trained cadre** of experts who possess ordnance skills necessary to help the Army meet any future contingencies.

Vintage Facilities Inadequate

Modernization is a **comprehensive** engineering and construction **program** that uses the technology and resources of the materials handling, machine tool, chemical processing, computer, and construction materials industries throughout the United States. Its chief goal is to completely overhaul and modernize the Army's ammunition plants, which concerned officials in the late 1960's felt were **inadequate** to meet future needs. When the Vietnam conflict broke out, the country had only 26 plants in the production base, down from the peak of 113 in World War II.

These remaining World War II and Korean War vintage facilities were put to a **hard test**. During the 1950's most of the procurement budget was devoted to deterring nuclear war, with little allocated to provide for the possibility of limited conventional war. Laid-away facilities required proper cleaning and preservation. With little money available, **maintenance suffered**. Problems arose with leaky valves, corrosion, tube sleeve failures, gasket deterioration, and machines that were out of tolerance. Parts could seldom be replaced off the shelf, while one-shot fabrication jobs were usually very expensive even when they could be arranged with commercial sources.

Capability Endangered

Available funds were used to acquire only those modern facilities essential to expansion, introduction of new items, and replacement of worn-out facilities and equipment which supported the conflict. As a result, production facilities had reached the point where equipment could **not be reactivated** without extensive rehabilitation or replacement after being laid away. In the event of a future emergency, such a situation was fraught with danger.

Production Base All Encompassing

The ammunition production base is **national in scope**. It includes production facilities, related industrial production equipment, and associated manufacturing technology and methods required to support the Department of

Defense's procurement and production of ammunition.

Army Sole Manager

The Army is DOD's single manager for **conventional ammunition** and is responsible for the entire base. There are government-owned contractor-operated (GOCO) and government-owned government-operated (GOGO) ammunition plants; production equipment packages in industry and those which are in central storage and/or under the Defense Industrial Production Equipment Center (DIPEC); and contractor-owned contractor-operated (COCO) plants.

Twenty-five GOCO plants are in the base, two of which are being declared excess. There are also **125 COCO** plants with 345 production lines (plant equipment packages, PEPs) which utilize government owned or a mix of government and privately owned equipment.

GOCO plants mainly manufacture **propellants and explosives**, metal parts, and small arms ammunition, and they also do the loading, assembling, and packing of ammunition items. Plants in the industrial sector make mostly **fuzes and metal parts**.

Lethal Components Controlled

The reason that DOD is deeply involved in making certain products such as small arms ammunition, propellants and explosives, and metal parts is due to the large capital investments required for facilities which have **no civilian use**, the government's extensive investment in such facilities to support previous conflicts, and the longstanding policy of the Army to control the lethal portion of munitions manufacturing. Also, industry does not have the capability to produce extremely **high level** requirements to support a potential conflict.

Bridging the Technology Gap

The modernization effort has had its share of problems. The base was **obsolete** in nearly every respect, making it necessary to modernize drastically in most instances. There was also a marked decline over the past twenty years in the **number of people** with ordnance-related skills to operate the remaining usable equipment.

Precision Metalworking Mandatory

Then, too, **new developments** in ammunition often required new production processes and equipment. For example, a 155mm high explosive M107 projectile is manufactured of medium carbon steel and has heavy walls that are relatively easy to forge. The only assembly work is the pressing of the rotating band into a groove. It is a relatively **simple** heavy steel forging. Its successor is the 155mm high explosive ICM M483. The body of the projectile has **several pieces** of thin walled high-strength steel, with a glass filament winding around the middle section of the projectile. The thin wall requires greater precision in forging and drawing operations and requires a special process for application of the rotating band.

New Fuzing Technology on Way

Another example is the conventional mechanical time fuze—MT, SQ, M564—used for air bursts with 90mm through 8-inch artillery rounds. The fuze contains a precision clock type safing and arming device manufactured by the **watch** industry. This industry has all but **disappeared** from the United States. A new electronic time fuze, XM587, is expected to replace the clock type fuze in the next few years. It relies on electronics for all of its timing functions except safing and arming. The new fuze relies heavily on the skill base in the **electronics and semiconductor** industries.

Bridging the technology gap was a challenging task, particularly in those areas that have no civilian counterpart. There is **no industrial counterpart** for most of the propellants and explosives and load, assembly, and pack manufacturing operations required for munitions. For instance, the last United States black powder plant was designed in 1892 and built in 1919.

Convert to Continuous Processes

Practically all current assembly involves a **great many hand operations**. Batch processes must be converted to continuous processes in order to take advantage of new materials handling techniques and to improve the safety of operations.

Another problem is **computerization** of the material handling, process tools, and inspection systems needed to achieve the desired operating economics and to decrease expensive direct labor. The new systems must be capable of **ECONOMIC LAYAWAY FOR PERIODS OF TEN YEARS** or more, a situation that is not encountered with most facilities in private industry. Computer manufacturers, for example, do not design their equipment for that kind of ownership. They make provisions for a few months of layaway, but certainly not several years.

Skills Juggled—Lack Specs

The know-how of management and skilled personnel and the environmental, occupational, and health regulations vary from plant to plant. These differences must be accommodated in such a way that the regulations are satisfied and that the **private sector is encouraged** to remain in the base and participate in the modernization program.

In the plant equipment package area, the Army faced an unusual problem. **No adequate data** exists that accurately describes the current status of this equipment nor are detailed specifications available. Without a knowledge of specifications, modifications, conditions, and accessories of present equipment, it is difficult to optimize the selection of machinery and equipment to modernize lines. It was necessary to implement a **Condition Assessment** Program before modernization could start.

Pacemaker System Applied

Modern technology is used in all facilities, even though at times there is a temptation to modernize with an older process for expediency and economy. The more costly modernization program eliminates or minimizes pollution and also occupational safety and health problems. Designs are tailored for energy conservation and, wherever feasible, flexibility in use of alternate fuels.

The first **full-scale plant** is built as soon as technology is available. It is located at a privately owned or government owned pacemaker (sometimes called **core facility**) installation. A pacemaker installation is one that has the proper combination of good management, strong

engineering, a history of remaining in the ordnance business **through peace and war**, and good future prospects. Plants are modernized or expanded to meet current production first. A balanced capacity to meet total mobilization requirements is provided through development of follow-on facilities.

Concerted efforts are made to **keep industry involved** in all phases of the program—engineering, equipment fabrication, construction, and subsequent plant start-up operation. Designs and operating data are provided free of charge to private firms that wish to invest in munitions manufacturing facilities and become part of the production base.

Expanded Capacity First Priority

The highest overall program priority is expansion of the base to meet current production. (Expansion as used in this article means the establishment of new production capacity.) The next priorities are to expand and then modernize to meet **mobilization requirements** specified by the Office of the Secretary of Defense and the Department of the Army.

Quality of Life A Guide

There are also **subpriorities** within the major categories. Those projects with greatest improvement in occupational safety and health are given first priority; those with significant pollution abatement benefits are given second priority; energy conservation is third priority. Replacement of worn out/unreliable facilities, achieving an economic payback, and saving of **critical resources** are other subpriorities. Most projects have these factors in varying degrees. A computer program helps to sort out overall priorities for a year throughout the program.

Over $2 Billion At Work

At the present time, there are over 387 active engineering and construction projects under way, reflecting a total expenditure of about 2.3 billion dollars. Included is a single base **propellant plant** under construction at the Radford Army Ammunition Plant which has a capacity of approximately two and one-half million pounds of propellant per month; the completed installation is expected to cost about forty-five million dollars. The contract was awarded in August 1972 and the plant is expected to be completed in October 1977.

Metal parts facilities for the 155mm conventional high explosive round are nearing completion at the Scranton and Louisiana Army Ammunition Plants. These facilities have a combined production capacity of approximately 380,000 rounds per month and are being modernized at a cost of about ninety million dollars.

The design of a plant to **continuously melt and pour** explosives into shells was completed recently. This plant is expected to load a million rounds of conventional 105mm ammunition per month, using about twenty-five production people per shift.

Revolutionary Methods Implemented

Equipment to manufacture **precision fuze parts** has been acquired and is presently being installed at a number of fuze plants around the country. This equipment is valued at about five million dollars and is of **foreign origin**, as there is no source of clock and watchmaking equipment in the United States.

Avoid Foreign Dependence

Product and process designers are busily engaged today—as they have been for the past four years—on designs that do not use foreign equipment for precision components. **Process innovations** are strongly encouraged in this area.

Several **assembly and pack-out** facilities for loaded ammunition have been designed and are under construction at the Kansas, Iowa, Lone Star, and Joliet Army Ammunition Plants.

Environment Not Ignored

Environmentally, the old acid area at the Volunteer Army Ammunition Plant was a **serious polluter**. Today, Volunteer enjoys the same freedom from pollution provided by modern technology as does industry in its chemical plants. There was also a pollution problem at the Scranton Army Ammunition Plant—the billet heating furnace belched black smoke within the building. A new rotary hearth furnace has been installed which is atmospherically controlled; in addition to **eliminating pollution**, it greatly reduces scale and consequently the amount of steel necessary in the production of the projectile.

Labor Reductions Vast

At the Twin Cities Army Ammunition Plant in Minnesota, primer insert machinery was obsolete and **labor intensive**. A new primer insert machine was developed by the FMC Corporation which operates up to 1,200 rounds per minute with a very low reject rate. The primer insert submodule features 100% inspection, greatly reduced cost of operation, dramatically **reduced labor force**, and greatly increased safety of operations.

At peak times at the Indiana Army Ammunition Plant, powder bags were **hand sewn** by almost 3,000 people. Loading and connecting the bags together also was done by hand. A modern automated machine has replaced the old manual type sewing machines, each of which new machines **replaces about thirty-three** of the manual sewing machines.

Specifications Deficiency Surmounted

Visits to producers who have plant equipment packages have been completed under the Condition Assessment Program. Condition assessment results will be incorporated into the determination of **"what" and "how"** to modernize.

Industry is deeply involved in this program—assisting in technology surveys, participating in manufacturing technology development, and assisting in the design of process equipment and construction and installation of facilities. Ultimately, **private industry operates** the completed facilities.

In summary, the Modernization and Expansion Program is a **major step** by the Department of Defense and the Army to modernize the technology and production facilities for conventional ammunition created during World War II.

Integral Plans Review A

Super Management Required

Seven billion dollars of capitalization committed over the next twenty years commands a "no stone unturned" approach from the Munitions Production Base Modernization and Expansion program managers—those who are charged with directing the implementation of this massive undertaking. With so large a portion of the nation's resources invested to completely renovate our military capability for ground warfare, **every means** is being taken to achieve objectives. These means include development of the latest manufacturing technology, the most sophisticated management techniques, and the most effective communications possible to keep the services and industry fully informed of progress.

Prior to the initiation of the modernization effort, the Army's ammunition production facilities were essentially of World War II **vintage** based on process technologies of the 1930s. Conversion of these facilities into a modern, efficient, reliable production base that can support the full spectrum of the sophisticated munitions of today and tomorrow is a **massive undertaking**.

ManTech Effort Drives Program

The program was initiated in 1970 and will cost about $7,000,000,000 (uninflated); it will take 20 years to complete. To ensure that this program uses the most modern production processes, it is driven by a vigorous and far-reaching **$40,000,000 per year** manufacturing technology effort (Figure 1).

Management of the program requires consideration of an unusually broad range of technologies. This is often quite surprising to those not familiar with the program, since they tend to associate munitions manufacture with propellants and explosives and simple shell (metal parts) operations.

In reality, the production of a **single round** of ammunition may involve processes for manufacturing electronic or fluidic fuzes or high strength composites, conducting laser inspection or automated testing, or implementing highly advanced material handling and packaging techniques. The facility may also use advanced systems to abate pollution, improve safety and health, and conserve energy. Relationships between the commodities manufactured, their manufacturing components, and technology areas are shown in Figure 2.

Another **popular misconception** about the munitions production base is complete government ownership and operation. While the government owns much of the propellant, explosive, and loading facilities because of their lethal nature and exclusive military application, they are operated under contract by industry.

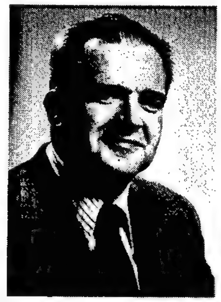
Metal parts, fuzes, components, materials, and countless other ingredients that go into a round of ammunition are almost exclusively made in industry. Therefore, our technology program is very broad, assessing not only the government-owned portion of the base but also the industrial base.

Given this diversity and magnitude we need a highly **responsive management** system to ensure that newly modernized and expanded munitions production facilities incorporate state-of-the-art technology.

Products Trigger Technology

Management of the program includes development of the requirements for technology. This is often triggered by product requirements; the types and quantities of munitions required and procured for inventory and produced in the event of mobilization. These requirements are normally **revised annually** and often in-

ossibilities



JAMES J. PRITCHARD is Chief of the Plans and Analysis Branch of the Program Management Division at the Project Manager's Office. As such he is responsible for planning the Manufacturing Technology Program in support of the Project Manager's Facility Program.

He is a graduate of New Jersey Institute of Technology, where he received his Bachelor and Master's degrees in Engineering. A licensed professional engineer, Mr. Pritchard is active in engineering society affairs and currently is a member of the Executive Committee Safety Division and Vice Chairman of the North Jersey Section of the American Society of Mechanical Engineers. He is also an active member of the National Society of Professional Engineers, Institute of Electrical and Electronic Engineers, American Institute of Industrial Engineers, and the American Defense Preparedness Association.

clude a significant number of new items. An analysis is made to see whether the existing production base satisfies these requirements, both from capacity and process standpoints. If no capability exists or capacity must be increased, a **need for process technology** may exist.

Frequently, excess capacity from production of an item phasing out of use is converted to a newer generation munition. This **conversion** may likewise require new process technology. We also consider modernization from the context of existing processes. Can we make improvements to enhance readiness, lower production costs, or improve quality? If so, a new technology application may be justified. Other requirements may be mandated by executive order, legislative action, or national interest—such as pollution abatement, occupational safety and health, and energy conservation.

Planning Integrated

Once the need for process technology has been established, a manufacturing technology program is formulated as shown in Figure 3. First, a **technology assessment** is made taking into account technology requirements, the state of the art, and technology forecasts that include the probability of attaining the desired technology.

The resulting technology assessment is used to generate technology guidance covering each specific commodity area and indicating in broad parameters the type of process technology desired. These **technology guidance "packages"** become the basis for detailed project proposals and submissions.

Following project submission and prioritization, we prepare a computerized, time-phased master technology plan. It includes all required manufacturing technology projects, both ongoing and for a five-year forecast period.

Program priorities play a major role in this master plan. Funding limitations preclude the accomplishment of all projects in their earliest year of attainment. A critical evaluation is made of each project to determine relative importance or priority. Consideration is given to the technology project's **relationship** to a scheduled facility project. Is completion of the technology project critical to the timely execution of the facility project? If so, when is it required?

Avoiding slippage of our facility program is of major concern. A relatively minor technology effort could jeopardize a critically needed, high cost facility project. Economic payback is a prime consideration. Some projects

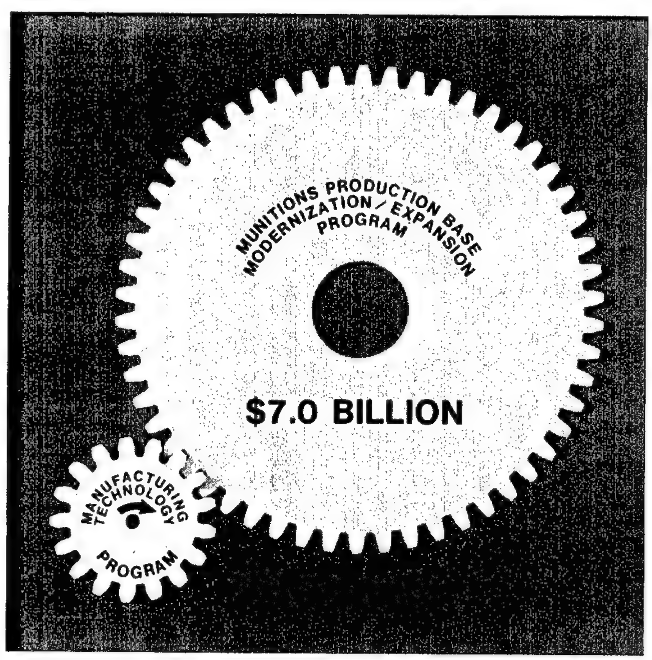


FIGURE 1

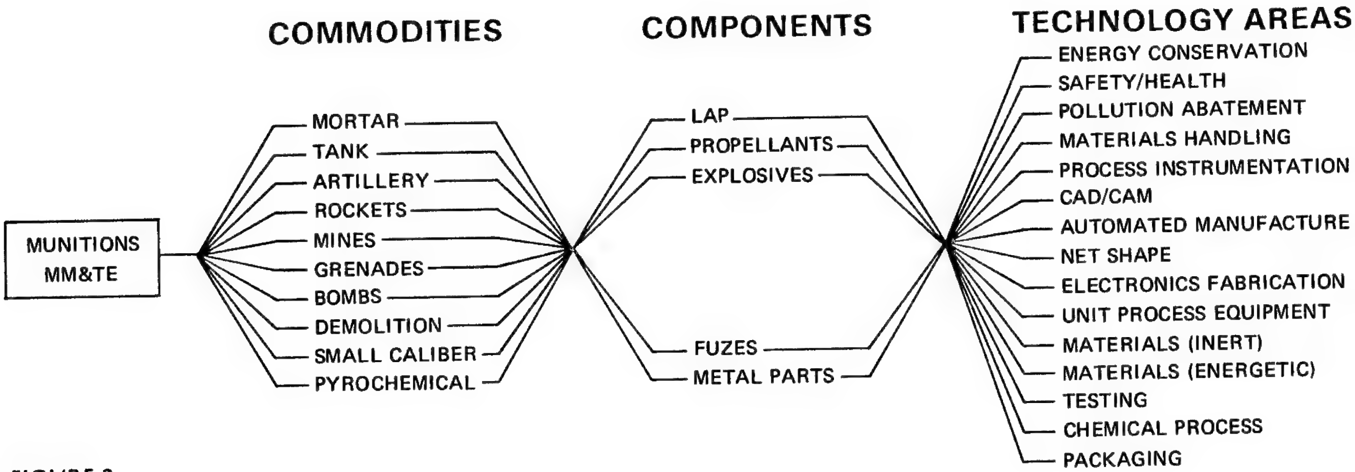


FIGURE 2

are beneficial in terms of labor, material, or energy savings, reduced capital investment, and/or maintenance/reactivation costs. **Delay in implementation** may result in failure to realize very significant savings. Delay may also be intolerable in the case of mandated projects—such as pollution abatement or safety and health.

The program is appraised by a high level Technology Review Board chaired by our Deputy Project Manager, Mr. Darold Griffin. Membership includes technical and scientific directors from Armament Command Headquarters and product and technology organizations. Sometimes outside consultants are included. This **Board appraises** the program from an overall standpoint—how well it meets our broad program goals and objectives.

Typically, the Board does not look at individual projects but considers the **total effort** by areas of technology or commodity relationships. In addition, the Board evaluates specific problem areas where a well-rounded technical opinion is desired.

Graphics Streamline Management

We employ a number of tools to plan and carry out the program. We consider **computer use** essential, because we must control several hundred technology projects from schedule, cost, and technical performance standpoints. Each project has numerous life-cycle milestones, critical interfaces, and time-phased relationships to facility projects. Our automated data processing (ADP) resources include graphic, batch, and teletypewriter terminals along with various display systems. This capability is supplemented by Picatinny Arsenal's extensive mainframe computer facilities and other DOD networks.

Our emphasis in the ADP area is on **managment-oriented displays**, graphical outputs, and interactive systems as opposed to generation of reams of tabular data. We also use a data base management system to provide flexibility by supplementing the various ADP programs. By generating lists of various combinations of data, we satisfy the needs of users **without writing** a program for each request. This ability to query data through data base management techniques proves helpful in both our facility and technology programs.

In formulating our Five Year Plan, we use a computerized system to get an Integrated Engineering Plan (IEP). The IEP contains **basic project information** and data such as project number and title, technology category(ies), facility project and munition item relationships, funding profile, implementation data, project evaluation and recommendations, responsible engineer, and the organization responsible for executing the project.

In addition to the IEP, **supplemental outputs** are available that include the basic project file, stratification of projects by technology category, project engineer and responsible organization, fiscal year, and product or facility project relationship.

After we achieve the master plan for accomplishing our program objectives, it is necessary to provide the means for assuring timely and efficient execution of the program. This is accomplished through various **performance measurement** techniques. In terms of scheduling, we use a computerized milestone reporting system whereby the important events for each project are identified, scheduled, and reported.

Communications Monitors Status

Efficient management requires effective communications. Planning and execution of our program involves coordination with higher headquarters, government development centers, manufacturing plants, other DOD services, civilian agencies, industry, and trade organizations. To ensure effective coordination, we have a broad-based communications program.

We hold **periodic reviews** with the technology developers. Project engineers, in the company of their commanders and directors, report on projects considered

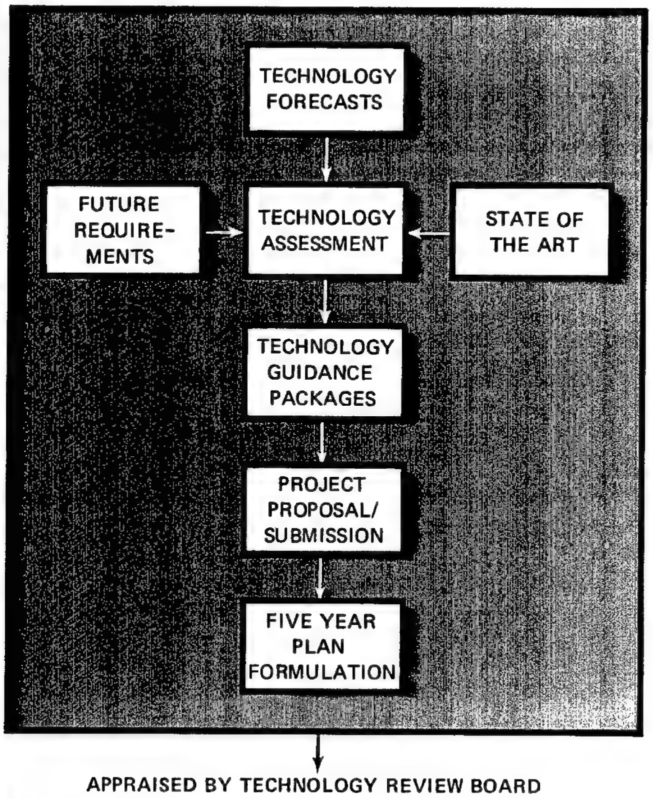


FIGURE 3

to be in a critical or problem status. The review covers progress since the last presentation, any schedule slippages, funding status, and recommended actions or decisions required.

We also have **close contact** with the item developer to learn early of new item development programs or product improvements. This affords proper phasing of our engineering and facilities projects to support production.

Services, Industry Trade Know-How

Another facet of communications is technology transfer. The Manufacturing Technology Advisory Group (MTAG) fulfills this among the services. MTAG is an **interservice coordinating group** with members from the Army, Navy, and Air Force. The Ammunition Subcommittee, one of six specialized groups, is used to inform the other services of our technology program while in turn keeping abreast of their efforts.

Another technique used to improve communications is our **information bulletin**, "Manufacturing Technology Topics". It is published quarterly and distributed to government and industry groups associated with the program. The bulletin serves a number of useful purposes.

Specifically, it disseminates in an informal manner the manufacturing technology developed under our program, as well as selected areas of the munitions technology programs of the Army and Navy. The bulletin also **solicits solutions** to specific manufacturing technology problems associated with the Modernization and Expansion Program.

In this manner, a concerted effort is made to avoid "reinvention of the wheel", or duplication of effort. Also distributed are copies of "Technology Briefs", one-page writeups on a technology effort. These consist of a photo, short abstract, summary of the project, and a **point of contact** for additional details. Through these approaches and the ManTech Journal, we hope to achieve wide dissemination and effective technology transfer.

New Ways Sought

Management of the Technology Program is a large and complex task. Individual manufacturing technology projects and our management system represent state-of-the-art undertakings. Ours is a **never ending task** of looking for new tools and techniques to improve the productivity of the ammunition production facilities and the management of this critical, broad-based technology program.

Less Effort Expended

New Inspection Tools To Save

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A key element in our Munitions Production Base Modernization and Expansion program is the use of automation and high-speed production operations where feasible to reduce labor requirements per unit of product. These new operating conditions necessitate changes in inspection methods.

Inspection must keep pace with production and, preferably, be in-line and real-time to immediately identify out of control production, minimize dwell time of product waiting for inspection, and maintain inspection costs and manpower demands at a manageable level.

Since the modernization and expansion of the ammunition production base involves acquisition/renovation of facilities and equipment, it differs basically from a program concerned chiefly with the acquisition of materiel. To support our program, several objectives have been established:

- Assure acquisition of equipment or a system that produces an acceptable product at the required rate
- Treat equipment characteristics pertaining to reliability, availability, and maintainability (RAM) as design parameters of equal importance with other technical and functional parameters early in the design process
- Perform and document accurate and independent evaluations of designs, equipment, and systems
- Use system/equipment demonstrations to verify that QA/RAM requirements have been met.

A **major thrust** of the product assurance program is to minimize the expenditure of effort on equipment acceptance testing and product inspection. **Product testing** is minimized by employing the latest inspection and test philosophy and equipment. **Equipment acceptance testing** is controlled by a test plan which delineates management controls and interfaces.

Production Simulated by Computer

During the design phase we examine specifications using predictive techniques to ensure that design production rates and RAM characteristics are achievable with the proposed design. A general-purpose computer program to simulate the operation of a production line was developed to do this.

This program uses a "Monte Carlo" technique and utilizes repair times and failure rates as inputs to the model. The model simulates a statistically significant number of production cycles and permits us to calculate availability of each operation in the system. It also indicates the number of units produced in the series of simulated runs.

From this information, we determine whether we can meet the system production rate and identify those operations that require modification. A simplified flow diagram shows the interrelationships of this system (Figure 1). It is a useful tool in decision making in that it **yields comparative information** on stop and redesign versus continuing on to equipment fabrication. It is also valuable in assessing potential savings associated with value engineering proposals.

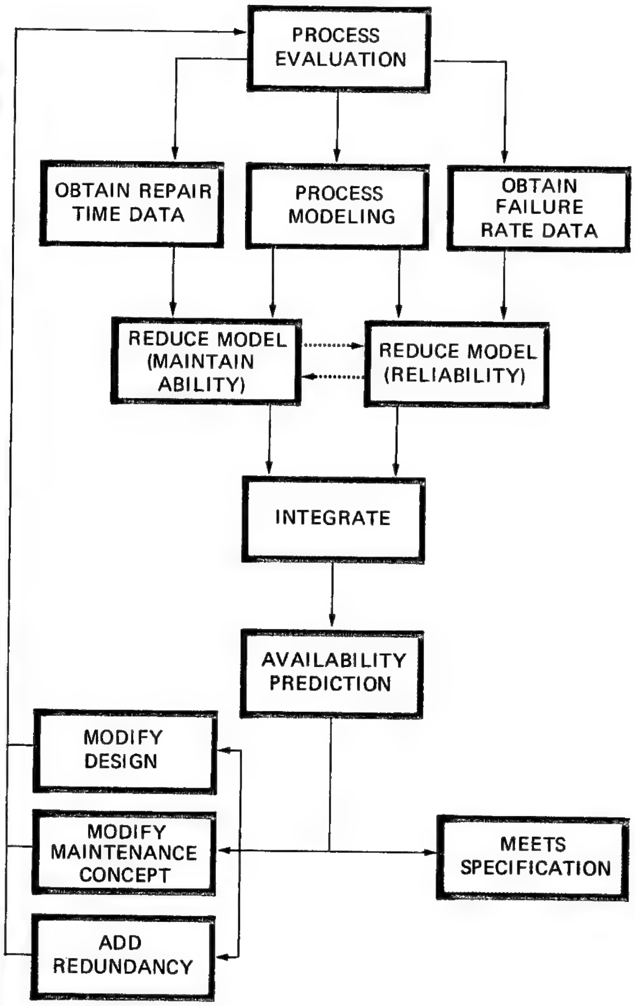


FIGURE 1

Product assurance engineers associated with modernization keep abreast of the field and use emerging technology to the full extent of its applicability. Since several aspects of munitions production are unique—especially the manufacture of propellants and explosives, fabrication of flaw-free shell and containers, control of explosive fills, and loading, assembling, and packing of munitions—we support a manufacturing technology program which addresses needed inspection technology in specific areas.

Explosives X-Rayed Now—Radiology Later

The quality of **cast high explosive** in high setback artillery shells has classically presented the Army with an inspection challenge which it previously was incapable of meeting without undue reliance on human judgment and excessive X-ray film costs.

Start-up in the near future of an ammunition plant designed to load one million 105mm M1 high explosive (HE) projectiles per month led to **two technology projects** addressing the problem on a short and long-term basis. They are: (1) short term—AXIS (Automatic X-Ray Inspection System) and (2) long term—AIDECS (Automated Inspection Device for Explosive Charge in Shell).

AXIS

Engineers are developing a modern, automated melt-pour system for the mass manufacture of HE-loaded 105mm M1 projectiles. This system will load a minimum of one million projectiles per month. Current plans are to use one Linatron (4 MEV) **X-ray machine** to handle the inspection requirement, coupled with automatic film processors to expose the film automatically. **Eight human film readers/shift** are required for 100% inspection.

The problem with this approach is that of the **doubtful reliability** and repeatability of human radiographic interpreters in high-production situations. There is skepticism over the validity of visual image analysis at all plants involving repetitive high-production radiographic inspection of artillery ammunition.

In view of the fact that critical defects in HE artillery shells cause premature detonations, fatalities, and loss of expensive equipment, the requirement to improve our present radiographic inspection process is of the utmost importance. We started a project directed toward the **elimination of the human element** in the present X-ray analysis.

Digital Images Shown

Two concepts are under consideration. One is centered around the use of a Vidicon System and the other around a Laser Scanner.

In the **Vidicon System** a standard light source illuminates the X-ray. A TV camera or a Flying Spot Scanner translates the illuminated X-ray image into an analog signal. The signal is converted in an Analog/Digital (A/D) Converter. The digital image is stored in a memory. A correlation scheme is applied to correct for image variations to X-ray geometry and shell positioning.

In order to extract actual defect information, a subtraction process is applied either by use of a standard image or application of gradient techniques. Algorithms will be developed to compare the defect information with the specifications. This system is graphically described in Figure 2.

In the **Laser Scanner** technique the laser beam penetrates the X-ray, and variations in light intensity are translated into an analog signal. The analog signal is converted into a digital signal and stored in a memory as in the Vidicon System.

Within the micro processor, digital filtering techniques are applied. Defect areas are located by a gray normalization and threshold technique. A shrink process is used to further define the defect area's physical parameters. The defect area locations are then registered to correct for image variations due to X-ray geometry and shell positioning.

The defect information is compared with the specification requirements to arrive at a decision. This

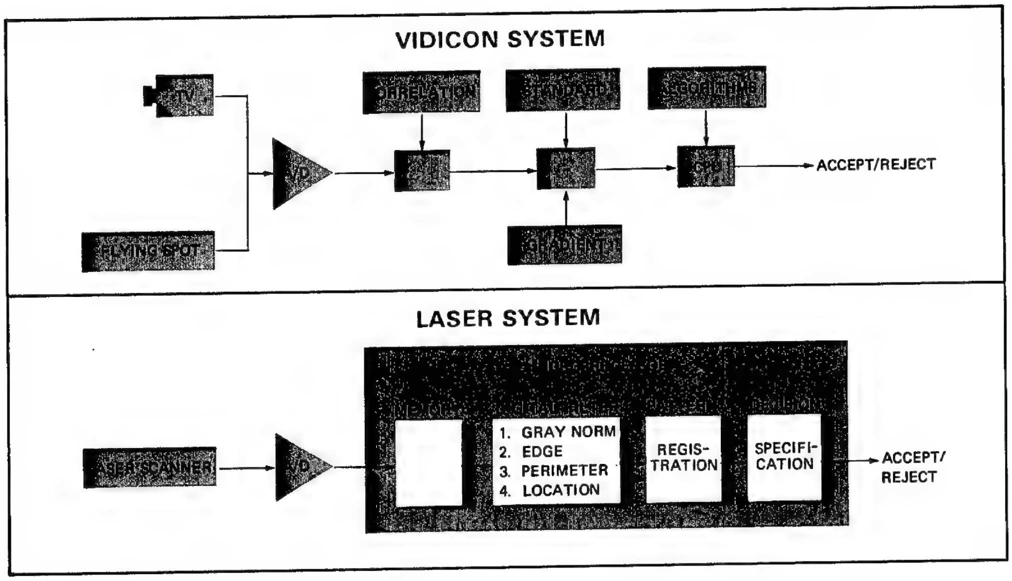


FIGURE 2

system also is graphically illustrated in Figure 2. We expect to **save $160,000 per year** at the design production rate in addition to improving reliability of the inspection by eliminating the eight film readers.

AIDECS

This test uses a **filmless**, real-time automated inspection fixture utilizing penetrating radiation to volumetrically inspect (100%) the high explosive within a 105mm shell at production rates estimated to be 44 shells/min. Defects within a shell will be identified as to type—i.e., base separation, cavitation, piping, location, and size. In addition, the system will automatically remove the defective shell from the line.

Penetration Radiation "Counted"

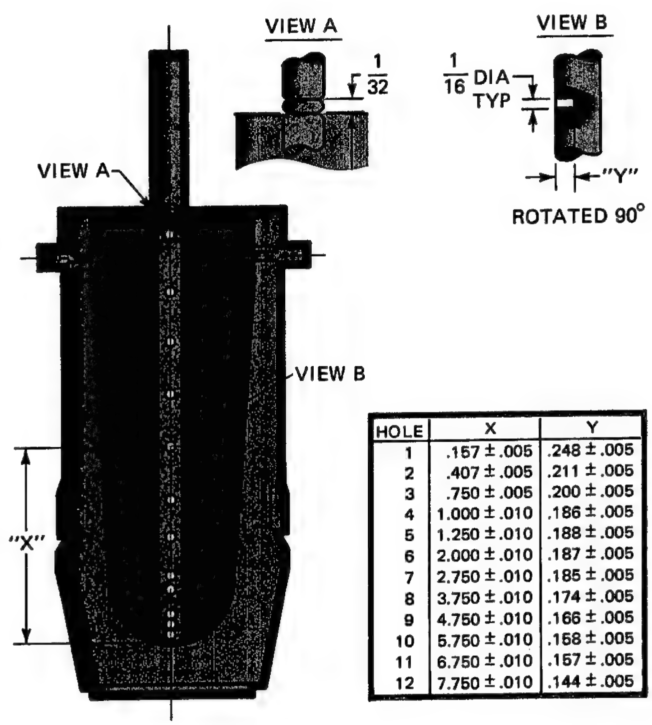
Inert calibration and verification standards have been developed reflecting various defect characteristics. As an example, Figure 3 shows the calibration standard, which is made up of the lower 9.5 inches of an M1 shell. It is filled with a plastic epoxy and a rod inserted containing 1/16-inch-diameter holes to simulate minimum cavitation defects that must be identified, measured, and located by the inspection system. This has been accomplished in the laboratory using Compton **scattering of gamma radiation** as the gaging medium.

Figure 4 shows a schematic diagram of the lab setup. A Cobolt 60 source is collimated to a beam ⅛ x ⅛ inch which penetrates thru the shell. As the beam passes thru the shell a portion of the gamma radiation is scattered by interaction with the filler material. A sodium-iodine detector "listens" for this scattering.

When there is no material in this volume, such as when cavitation exists, the source radiation has nothing to intersect with, thereby dramatically reducing the scattered gamma radiation. Evidence of this is shown in Figure 4b, where the #10 hole in the calibration standard is rotating in and out of the inspection volume. Here, the abscissa is the angle of rotation from 0 to 360 degrees and the ordinate is the photon count rate in thousands per second. The **dip in the count** indicates the influence the hole has on the amount of scattered radiation.

Figure 4c shows an absolute difference in count rate due to the base separation created in the calibration standard by retracting the rod 1/32 of an inch. Here, the angle of rotation is of no consequence since base separation is concentric with the longitudinal axis (the axis of rotation).

In the production prototype the shell rotates and translates up and down and sideways such that each and every ⅛-inch cube is inspected. The scattering information is stored in computer memory for each inspection



HOLE	X	Y
1	.157 ± .005	.248 ± .005
2	.407 ± .005	.211 ± .005
3	.750 ± .005	.200 ± .005
4	1.000 ± .010	.186 ± .005
5	1.250 ± .010	.188 ± .005
6	2.000 ± .010	.187 ± .005
7	2.750 ± .010	.185 ± .005
8	3.750 ± .010	.174 ± .005
9	4.750 ± .010	.166 ± .005
10	5.750 ± .010	.168 ± .005
11	6.750 ± .010	.157 ± .005
12	7.750 ± .010	.144 ± .005

FIGURE 3

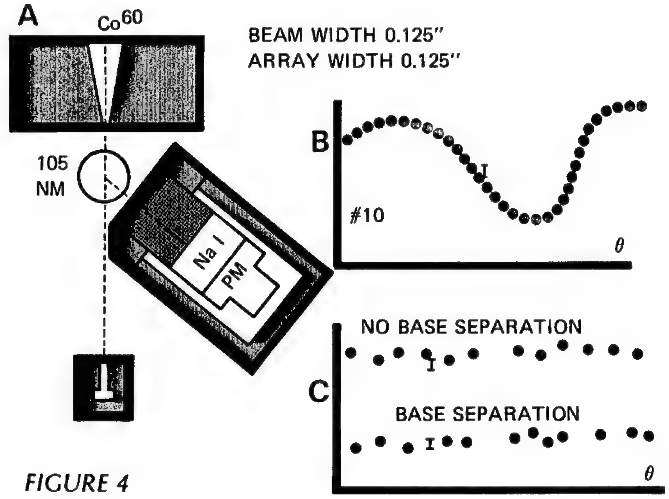


FIGURE 4

volume. Algorithms will then be performed on adjacent arrays of inspection volumes so as to identify the presence, type, size, and location of various defects.

Since the radiation source radiates energy 360 degrees, **multiple inspection stations** will be designed around one source. This will comprise a complete module. These modules will then be multiplexed to provide the required inspection rate of the load, assemble, and pack (LAP) facility.

Non-Film Concept in 1980

The AIDECS system has been scheduled for installation at an Army ammunition plant in the February to September 1980 time frame. It is anticipated that this program will incur a savings of two million dollars per year when compared with film radiography at mobilization production rates for 105mm projectiles. It will also provide **increased inspection reliability** when compared with the random image obtained by a single radiograph.

Production of the 105mm M1 projectile will be the base from which this non-film concept of penetration radiation inspection will advance from the laboratory to a production environment. Then, only equipment modifications will be required to fabricate other AIDECS systems for the entire spectrum of HE artillery munitions. It may also be possible to use the AIDECS concept for inspection of other types of munitions. It would be difficult to attach accurate potential savings with any confidence. However, once the AIDECS system is in operation for the 105mm shell, serious consideration can be given for both system modifications and redesign in order to tap the **vast savings potential** that the AIDECS system will provide.

Dynagun Okays Propellant Faster

Planned implementation of a continuous cannon propellant production facility at an army ammunition plant has generated requirements for **"on-line" ballistic evaluation** of charge density, so loading can occur shortly after manufacture. A continuous propellant production system has the advantages of high volume production and propellant uniformity.

Presently, loading density determination is made by confirmatory ballistic firings with use of a reference propellant lot and a time delay of several weeks or more. To solve the problem, the Project Manager sponsored a manufacturing technology project for the automatic acceptance of continuously produced propellant (AUTOCAP).

The intuitive solution of establishing a proving ground capability at the manufacturer's plant presents many **undesirable features**:

- Large acreage requirements
- Stringent safety precautions to preclude the risk of endangering existing explosive, chemical, and propellant manufacturing lines
- Specialized ballistic instrumentation demands to include temperature conditioning
- Weather restrictions
- Decentralization of proving ground test operation.

The most viable alternate to an on-site proving ground facility was determined to be a laboratory **ballistic simulator** or, as a minimum, a scaled-down gun which could fire inert slugs and which was small enough to be fired in a test tunnel of minimum sophistication.

A new laboratory device for accurate data acquisition has been developed to simulate the 155mm M1 high zone firing. The simulator, called the "Dynagun", was designed to be a **combustion chamber** to burn a small but representative mass of solid propellant grains.

The Dynagun is essentially an inertial mass with a sliding pressure seal accelerated by the pressure from the burning propellant gases. It employs an initial chamber volume that can be set from about 8 to 12 cubic inches, a bore diameter of 1.5 inches, and a piston-like, recoverable slug of about 33 pounds. The position of this keyed slug is monitored each 1/15 inch by two digital magnetic sensors for about one foot of travel after offering an opening area several times the slug cross section area.

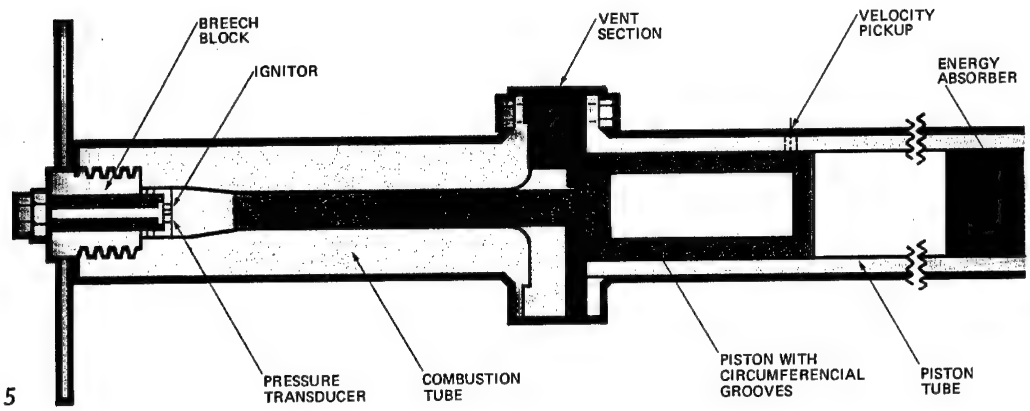


FIGURE 5

Data should be amenable to differentiation for velocity and acceleration. Chamber pressure time is also taken. A low level of shot start can be incorporated, and deceleration of the slug without damage at an expected speed of a few hundred ft/sec is a basic feature of the design. Figure 5 is a schematic of this simulator.

Loading Density Accurately Measured

The data required from each test is comprised of the **instantaneous average pressure** in the chamber and the **displacement of the piston**. Other than the approximate peak velocity obtained by measuring the amount of energy absorber crushed, all the useful data from each firing is recorded by photographing the display from three transducers on the face of a storage oscilloscope. Figure 6 shows a schematic drawing of the instrumentation utilized.

The Dynagun has been installed at an Army ammunition plant to test propellant in production. Correlation will be made with proving ground firings to test its accuracy in determining artillery charge loading weight. Preliminary results look promising. If successful, this system can be adapted for the acceptance of various types of propellants. **Inestimable savings** are accrued to the government as a result of reductions in manpower, time, and use of proving ground facilities.

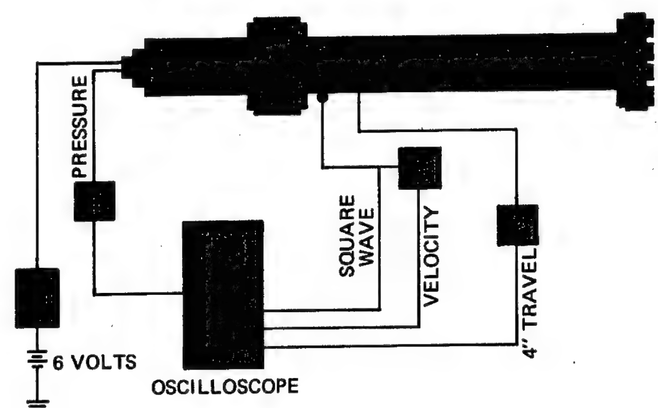
Propellant Tested by Computer

Currently, a closed bomb test (closed vessel testing of gun propellants) **for relative quickness** and **relative force** is utilized in the acceptance of all gun propellants manufactured. Testing is performed both on in-process samples for process control information and on final lot samples as a measure of ballistic performance.

Historically, these tests were performed in accordance with Method 801.0 of MIL-STD-286B, "Propellant, Solid: Sampling, Examination and Testing". The MIL-STD data reduction method involves recording a trace of oscilloscope output (pressure-rise rate versus pressure), physically measuring the trace, and **manually calculating** the data.

Usually, values of relative quickness are obtained at four calibration points and the results are averaged to yield a single value for relative quickness. Radford Army ammunition plant has successfully used this method for years, but it is **relatively expensive**, time consuming, and error prone.

As part of the AUTOCAP program, a completely automated closed bomb data acquisition and analysis system was developed. It reduced the analysis time from **24 hours to minutes**. Data from each test is automatically fed into an IBM System 7 Technical Data Acquisition System, where it is immediately processed and reduced to yield the desired relative quickness and relative force values. Graphic descriptions of both systems are shown in Figure 7.



Key: 1 = FREQUENCY/VOLTAGE CONVERTER
2 = POSITION INDICATOR AMPLIFIER
3 = KISTLER PIEZO COUPLER
4 = IGNITION SWITCH

FIGURE 6

A comparison of the closed bomb relative quickness and relative force data obtained by the IBM Data Acquisition System and those calculated from the oscilloscope indicate differences of less than 1 percent. As of April, 1975, the new system supplanted the oscillograph method on all of Radford's production of artillery and mortar propellants. During 1975, Radford has validated a cost savings of $21,500. Based upon projected buys, additional **savings of over $100,000** are anticipated in the next five years.

Chemical Analysis Computerized

Another improvement which has been accomplished in accelerating the acceptance of propellant is the acceleration of chemical analysis of samples from propellant lots.

The previous method required sixteen hours to prepare a sample and perform manual analysis of a trace from a gas chromatograph. The analysis time was reduced **from sixteen to two hours** by reducing the sample preparation time and linking the gas chromatograph to an IBM System 7 Computer. The data is automatically fed from the gas chromatograph into the computer where it is instantaneously analyzed to yield the chemical content of the sample. Pictorial descriptions of both systems are shown in Figure 8.

Implementation of this system at the Radford Army ammunition plant has resulted in a validated cost savings of $14,000 for 1975. Based upon current and future buys, additional **savings of at least $70,000** are expected in the FY 76–81 time frame.

Training Programs Implemented

In order to keep pace with the new product assurance techniques, the Project Manager's Office has been conducting a continuous training program in the product assurance area. This training includes all aspects of reliability, availability, and maintainability (RAM) and quality assurance. Short training sessions in specific areas are presented periodically. Arrangements recently have been made with the DARCOM Intern Training Center at Red River Arsenal to develop a RAM training package for Army ammunition plant and arsenal personnel.

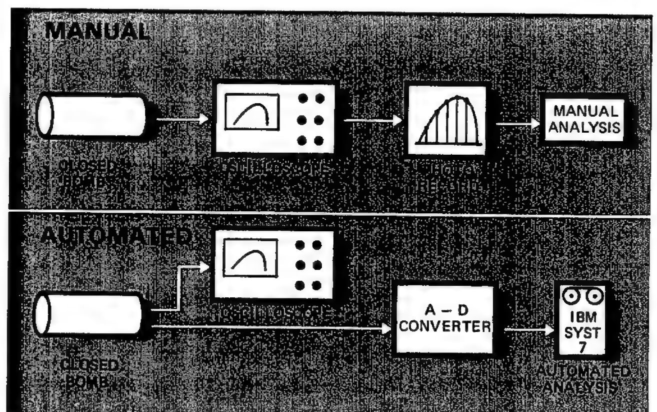


FIGURE 7

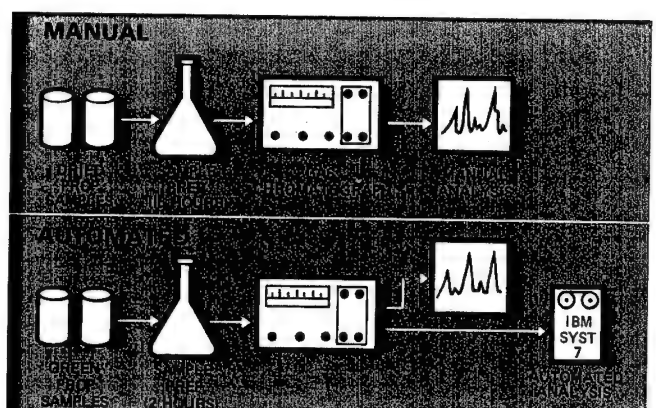


FIGURE 8

Safety Is Everyone's Business

Overdesigns Costly

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Deliberate programs of applied research by all three services jointly, by industry, and by contract research firms is paying off with substantial results in the area of safety for Army munitions plants. **New standards** are being set on not only structural requirements, but also on safe separation distances, hazard characteristics of munitions, and evaluation of blast effects.

The safety of personnel and the protection of valuable equipment present unique problems in designing and operating the Army's munitions plants, which are engaged in propellant and explosive manufacture as well as the loading and assembling of munitions items. Not only must they abide by **stringent industry requirements** associated with chemical and manufacturing plants; but they must cope with a product that is explosive.

The in-process materials may be inert, corrosive, erosive, flammable, or explosive, and individual facilities often are exposed to all these environments. **Appropriate safeguards** must be designed into the facilities to preclude catastrophic results in the event of an accident.

Design Manual Rewritten

Standard industrial plant construction materials, methods, and techniques are inadequate to meet these safety requirements. Recognizing this problem, Picatinny Arsenal scientists and engineers entered into a broad **tri-service program** of analysis, testing, and evaluation of structures designed to afford protection against the effects of an accidental explosion. One result of their efforts was the design manual "Structures to Resist the Effects of Accidental Explosions" (Army TM 5-1300) published in 1969.

This manual contains procedures, tables, and charts required to establish the environment of an explosion, including its output in terms of blast and fragments and methods for determining the **structure response** to resist the output.

From 1970 until 1972, Safety Engineering at Picatinny consisted primarily of providing guidance in the use of the design manual and reviewing the adequacy of facility drawings for the emerging Munitions Production Base Modernization Program in terms of **protective structure requirements**. In the course of these applications, potential areas for improving and refining the manual appeared.

In addition, requirements for safety engineering data and design information were increased to support new facility design and construction under the modernization program. Consequently, a program including **extensive testing** was initiated to establish data and procedures to supplement and/or modify the regulations and assist designers and engineers in developing the most economical facilities. Presently, this program is directed toward the establishment of new data for

- Safe separation and sensitivity criteria
- TNT equivalency
- Hazard classification
- Blast effects and structure response.

TNT Equivalency

Protective structure design criteria in TM 5-1300 are presented in terms of the blast loads generated by

spherical and hemispherical charges of TNT. When designing a structure to afford protection from the blast output of some **other energetic material** or charge shape, the designer must be able to convert the loading given in the manual for TNT into information which is pertinent for the material in question.

To accomplish this, tests have been conducted (and are continuing) where the peak pressure and positive impulse are recorded from charges of the same shape and composition found in the manufacturing process being designed. This data is then compared with the **blast output** generated by hemispherical charges of TNT detonated on the ground surface in order to determine the equivalent weight of TNT that will generate the same peak pressure and/or impulse at the same distance. In all cases, the effect of the booster used to initiate the charge is accounted for.

To date, test results have been obtained on black powder, nitroglycerine, Composition B, nitroguanidine, guanidine nitrate, RDX slurry, several pyrotechnic compositions, lead azide, lead styphnate, tetracene, and N5, M1, M26E1, M30A1 and NACO propellants.

Blast Output Predicted

Tests are under way on the various nitrobody/acid concentrations associated with both the present and proposed processes for the manufacture of TNT by the continuous process, as well as Composition A5 and M10 propellant. Additionally, an **analytical technique** for the prediction of the blast output of energetic materials is being developed. This technique will take into consideration the shape of the charge, its composition, and the standoff distance.

The accomplishments of this program have been shown to be related to direct savings benefits as well as improved structural safety. By realistically appraising the explosive blast output of a particular process, the facility layout can be **optimized** in terms of protective requirements and costs.

FIGURE 2

Safe Separation and Sensitivity Criteria Ascertained

New automated processes are making extensive use of **mechanized material handling** systems to reduce manpower needs. The separation distance of explosives, for instance, on a conveyor, must be ascertained so that the explosives will not propagate down the line in the event of an incident or accident.

These "safe" separation distances apply to both finished products as well as the in-process materials and are performed on an exploratory basis to find the suitable distance and then on a repetitive basis at that distance to provide a **reliability level** that is acceptable to the Army's


FIGURE 1

safety engineers before being introduced to the facility design.

Typical safe separation distances for explosive materials already have been established for 55 pounds of TNT and 60 pounds of Comp B in shipping boxes and 35 and 50 pounds of Comp C4 in conveyor buckets. Projectiles whose safe separation distances have been established include 155mm Comp B and 81mm and 105mm Comp B, both singly and in pallet loads on conveyors. Figures 1 and 2 depict typical test setups.

In some cases the present safe separation distances were **substantially reduced** (as was the case with 55 pounds of TNT and 60 pounds of Comp B in boxes). In several cases the required distances were newly established. But, most important, in still other cases the required safe separation distances were increased due to **unsafe conditions** found to exist under present safety regulations.

Sensitivity Determined

At the same time the effect of impact from both primary fragments (resulting from breakup of explosive casing) as well as secondary fragments (resulting from wall breakup or pieces of equipment) on the sensitivity of explosive end items and in-process materials has been investigated.

Testing of some specific cases, carried out at ambient and elevated temperatures, established a fragment **mass-velocity relationship** below which no detonation will occur. These work areas are being intensely investigated since they have a **broad impact** both on the modernization of facilities and operation of existing facilities.

Placement of equipment, safe separation distances between explosives, protective capacity of existing barricades, and improved design of shielding and cubicles are but a few instances in which these studies could be utilized.

Blast Effects and Structure Response

While TM 5-1300 provided a much needed capability to design and construct a structure which will provide protection against the extremely hostile environment associated with an explosive blast, it was soon recognized that the techniques presented thus far would **only solve part** of the problem. In order to meet production objectives and to economize on process equipment, it is desirable to locate the various structures associated with a particular line as closely as possible to one another.

Proximity of adjacent structures presents the problem, however, of subjecting these buildings to **overpressures greater** than a conventional structure is capable of withstanding in the event of an accidental explosion in an adjacent building. Since the techniques in TM 5-1300 are based on using reinforced concrete as the construction material, utilizing this manual for structures in the medium and low pressure regions **(less than 10 psi)** may not constitute the most cost-effective approach. Criteria for utilizing the wide range of construction materials in the blast environment were needed.

To bridge this gap, studies were initiated in two major areas:

(1) A determination of the **blast environment** produced from explosions in various types of structures

(2) An investigation of the **dynamic response** of structures when subjected to these blast loadings.

This work has produced results contained in a number of technical reports and papers covering such subjects as

- Blast pressures from cubicles with various degrees of venting
- Design of steel structures to resist the effects of high explosive detonations
- Primary fragment penetration characteristics.

Further work is presently being conducted in several other areas of interest. Testing was recently completed to determine the dynamic capacity of **tempered glass and steel** roof and siding panels such as are used on pre-engineered buildings. Here, the concern is that these elements do not become the "weak link" and present a fragment hazard to personnel inside an acceptor structure.

Tests will be started soon in a program to determine the loadings generated by the **simultaneous detonation** of several charges. This data is necessary to properly design a barricade which might be subjected to this type of load and, hopefully, to facilitate greater use of pre-engineered structures.

A computer program capable of performing an analysis of the **elastoplastic response** of frame structures subjected to blast loads is being developed. Since conventional structures must remain well within the elastic response region when subjected to their design loads, the commercially available **programs are limited** to this region.

Plastic Structure Response Needed

However, in order to achieve significant construction economies, it is desirable to design an explosion resistant

acceptor structure to have some plastic response (limited permanent deformation). With the new program, a designer will be able to predict the amount of **permanent deflection** a rigid frame will experience with a given load.

Full-scale tests of a pre-engineered building subjected to blast loads are scheduled for later this year. The current approach is to assume that all of the energy associated with the blast wave acts on the structures frame. This may not be true. It is likely that as the load is transferred from the siding/roofing to the purlin/girts and thence to the frame that these **components will dissipate** some of the energy as they deform.

This attentuation of the blast energy may enable the designer to use a lighter frame which will produce further cost savings. These and other studies being planned will extend the capability of the designer of blast resistant protective structures into areas which were heretofore never completely investigated.

Hazards Classification

Established procedures for determination of the hazard classification of propellants and explosives contained in existing regulatory documents (TB 700-2) are not applicable to the potential hazards during various stages of manufacture and assembly. To properly classify these materials, **new procedures** must be developed. Specific tests for in-process materials—such as slurries or propellants contained within their associated manufacturing equipment—are being established to accomplish this.

An example of this work was the determination of critical height of M1 propellant. These tests resulted in establishing the hazard characteristics of **specific granulations** of M1 propellant to modernize 105mm loading equipment at the Indiana Army ammunitions plant. The propellant was subjected to tests to determine critical height (above which the propellant will explode, not burn), diameter, effects of confinement, ease of transition from deflagration to detonation, reaction rate measurements, blast output, and self-extinguishing characteristics of the propellant.

Another example was determination of the hazard classification of M1SP propellant in an automated single-base finishing operation. A feed hopper containing approximately 500 pounds of M1SP propellant was designed with a **venting capability** to prevent an initiation by burning from progressing to detonation. Completed tests substantiated the adequacy of the venting provided and thus obviated costly protective structure requirements.

Advanced work in the hazard classification area is planned for a large number of munitions processes to develop standardized tests and procedures for **regulatory documentation**. This will enable operating agencies to perform tests and secure safety approval of the classification results attained.

Program Coordination

The Modernization and Special Technology Division of Picatinny's Manufacturing Technology Directorate draws upon the expertise of segments of both **government and industry** to accomplish the program.

The DOD Explosive Safety Board is the highest official organization involved with safety approvals. Within the Army itself, all safety offices up through the Army Materiel Development and Readiness Command level, the DA Project Manager's Office for Production Base Modernization, the Armament Command's munition plants (notably, Radford, Lone Star, Holston, Indiana, and Louisiana), the Huntsville Division Corps of Engineers, and both Frankford and Edgewood Arsenals have provided input to the program.

The **Air Force and Navy** are well attuned to the program, with the Navy's Civil Engineering Laboratory and Weapons Center taking part in and effecting selected portions of the program. Major tests have been conducted by the Army Test and Evaluation Command's Dugway and Yuma Proving Grounds and at the DARCOM depots of Tooele and Sierra.

Feltman Research Directorate scientists at Picatinny provide **basic research assistance** to the program, and the Manufacturing Technology Directorate's engineers are charged by the Project Manager's Office to make a final review of all modernized facility designs to ensure compliance with the very latest safety engineering data.

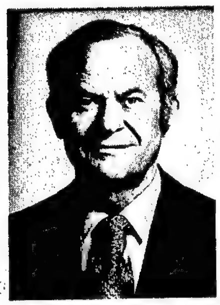
Industrial concerns are well represented as doers in the program, with typical participants such as the Illinois Institute of Technology Research; Southwest Research Institute; Ammann and Whitney, Inc.; Hercules, Inc.; A. D. Little, Inc.; Hazards Research, Inc.; and others.

With the **idea stimulation and interchange** of information that occurs, it is no wonder that the U.S. munitions industry is being modernized to the safest standards in industry.

The fact that visitors from all over the world have requested briefings and technical information generated by this safety engineering program attests to its success.

Royalties, Privacy Essential

Private Methods Spee



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The most effective manufacturing technologies available—**regardless of source**—are stipulated by the Project Manager for Munitions Production Base Modernization and Expansion in the program he directs towards updating facilities and equipment of the Army's ammunition plants.

The Army itself is a **significant information source.** Because of its extensive R&D programs and industrial contracts, the Army pays for a broad range of patents and proprietary data for the manufacture of military munitions, and its **ownership of data is unequaled** probably by any other institution, domestic or foreign.

Private Sector Not Overlooked

However, companies interested in advancing manufacturing technology to improve their competitive positions in the industrial/consumer marketplace also generate new processes. Many of these processes also may be used to manufacture munitions and thus modernize the Army's plants.

Normally, these processes are protected by **patents and proprietary secrets** that are held in "close hold" so that the owner can reap the rewards. The release of this data is limited to certain conditions and usually includes the payment of royalties. **Acquiring commercial data** is a major activity requiring close interaction of our engineering and legal personnel with the private sector.

Technology acquisition from the private sector is influenced by varying conditions. For example, one owner may limit his data to military use only, while another may offer an unrestricted license. Examples are the negotiations between propellants and explosives plants and the chemical process industry.

The establishment of our office in the early 70's to modernize the government ammunition plants brought manufacturing technology considerations to the forefront. Plans for process improvement at the plants required integration with **current and projected** production schedules. At all times, the technical staffs had to maintain an awareness of the need to program modernization and

rogram

maintain a continued readiness to meet any unanticipated war.

It was necessary for the staffs to initially determine what we had, what improvements were needed and where they were to be found. Thereafter, if located, we had to find out if they could be acquired for Army use.

Abreast of Developments

The Army already was prepared to begin answering these questions. Its engineering personnel and those of the contractor operators of its ammunition plants, as professionals, had **remained aware** of many of the new technological advances even while meeting "wartime" production schedules.

Additionally, most of the government plants are operated by industrial organizations. These companies were abreast of the new manufacturing technologies, and in many cases had **actual experience** with them in their own plants.

As an example, Tennessee Eastman Co., the parent of the contractor operator manufacturing RDX/HMX at Holston, Tennessee, had developed new catalysts and improved furnaces for acetic anhydride for their commercial products. Its competitors, Union Carbide, American Celanese, and others, had developed their **own know-how** for improved anhydride and derivative processes.

The industrial acid field had undergone strong competitive pressures for improving processes for sulfuric acid concentration and regeneration. The Hercules Powder Co., another contractor operator, had performed investigations for improving processes for nitroglycerine using a magnesium nitrate process.

Day and Zimmermann Co. and Silas-Mason Co., contractor operators of other GOCO plants, are well-known commercial architectural and process engineering firms whose wide experience and skills in the design of **chemical installations** we have been able to take advantage of. They utilize the most modern construction technologies.

Technology Search Conducted

When the government allocated resources to modernize its ammunition plants, the Project Manager marshalled the contractor operators and the Army engineers into a program that, at its initiation, already was able to provide answers to many of the questions for **identifying needed improvements**.

However, a contract was awarded in addition to Kaiser Engineering Associates to survey our government-owned manufacturing facilities, obtain the views and recommendations of our contractors, and ascertain the state of the art through a **comprehensive search** of all other possible sources of information, whether foreign or domestic. Our office assisted the search through other government agencies, consultants, and engineering firms scholled in the various phases of manufacturing technology. The modernization program was publicized with **industry associations**.

The investigations also led to new technologies reported in offshore publications by **foreign contractors**. In Germany, the company which invented the original process for acetic anhydride improved its method for manufacture by means of a pump which could save construction costs. Great Britain had a new red phosphorous process, and a Norwegian company developed the first process improvement for black powder manufacture in 100 years.

Having identified potential technology which could improve our base, the final step was the acquisition of the **right to use** the improvements in a modernized ammunition plant.

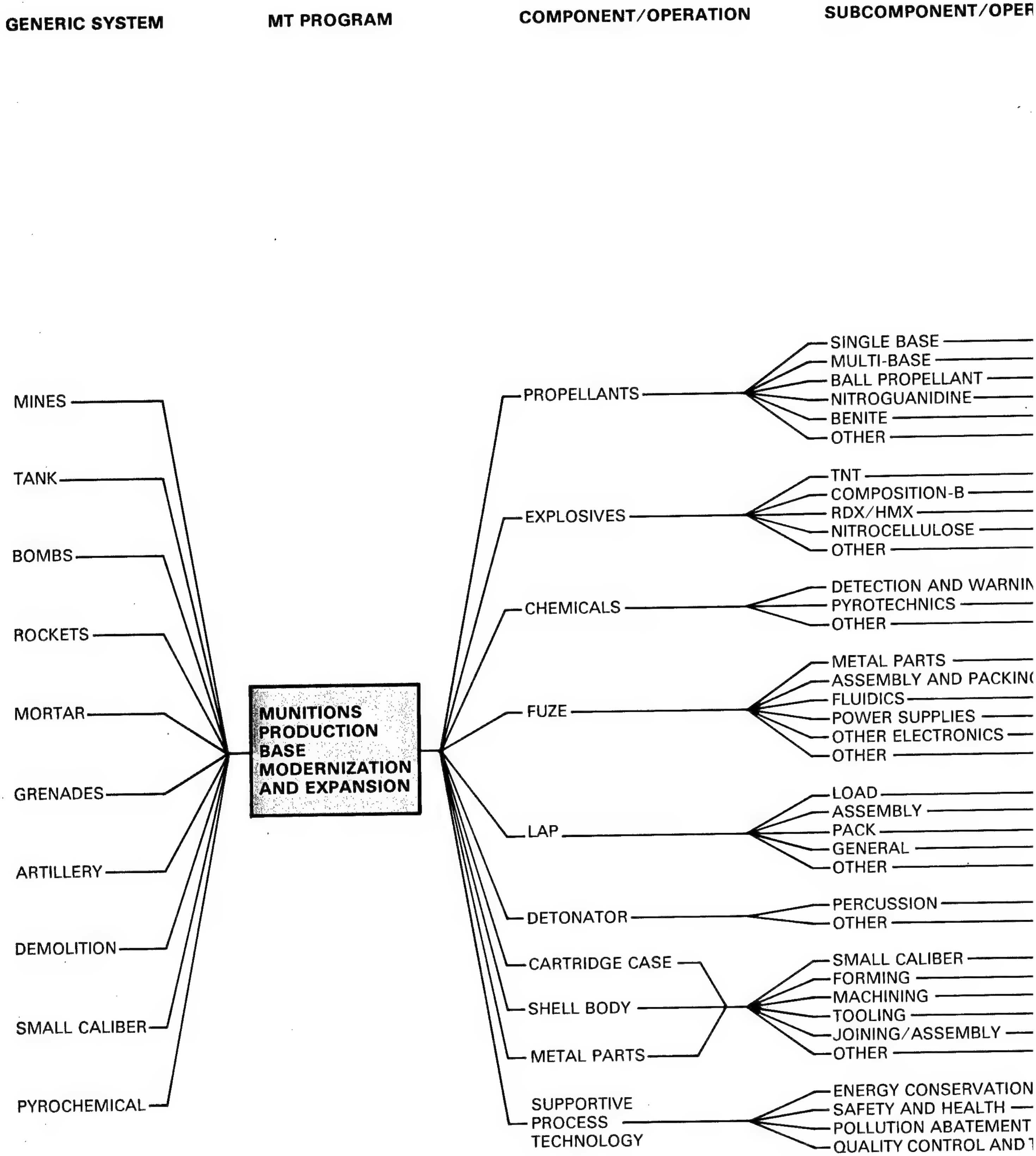
The Department of Defense policy for acquiring the right to use patent or other proprietary data has been developed over a span of years. The contracting authority for the acquisition of data in the DARCOM complex is the Command Counsel of DARCOM.

Proprietary Technology Stimulated

The **main thrust** in acquiring data, whether foreign or domestic, is to encourage private development of new technologies and to pay a **fair royalty** for the use of the data. This has been found to be the only way to encourage development. The following situation in manufacturing technology lends itself readily to this approach:

(1) Private developments usable for modernizing the ammunition plant complex have taken place.

(2) Most of the foreign data obtained has been from nations friendly with the United States.



TOTAL NUMBER OF PR
(Approximately half are
year funded)

SPIDERCHART **US ARMY MANUFACTURING TECHNOLOGY PROG**

...er of Projects in Each
...bcomponent/Operation Area

MT GOAL*: Reduce Manufacturing Unit Cost	Reduce Facility Capital Investment	Reduce Production Base Response Time	Improve Operator Safety and Health	Reduce Critical Resource Consumption (including Energy)	Reduce Pollution	TECHNOLOGY AREA*: Energy Conservation	Safety/Health	Pollution Abatement	Materials Handling	Process Instrumentation	CAD/CAM	Automated Manufacture	Net Shape	Electronics Fabrication	Unit Process Equipment	Materials (Inert)	Materials (Energetic)	Testing	Chemical Processing	Packaging	Fluidics Fabrication
1		1																2			
1	1	2															2	1			
4	1	3		1	1		1	1	3						2		2				
1		1															1				
1		1					1		1								1				
		1																1			
3		2				1	1		1	1		1					3				
3		3					1		1								3		2		
10	1	7				1		3	3								8		7		
2	1	1							1										2		
4	1	2	2				3		3						1		4	1			
			1				1												1		
6		5					9		8								1		8	1	
			1		1		1	1	1										1		
4	1	4										2			3						
6		5								3	1	3			1	1		4			
2		2										1			2						2
2		1										1		1	2						
3		5							1	1		2		3	1			3			
1		2	1				1		1	2		1			1			2			
1	1	1							1	1							1				
4		2							3			3								3	
1		1							1											1	
10		8					3		8			8			1		2			2	
2		2	1				1		2								1				1
1		1	1				1		1			1						1		1	
	1						1														
2	2	2							2	2		2	1		2	1	2	2		1	
9	1	10	1	1						1		1	4		2			5			
2	1	2													2						
1		1																			
5	1	4								1		1			4			2			
2		3							2						2			1			
				1		1															
			8				8														
			1		2		1	2													
6		3									1							7			

* Number of individual projects addressing this MT Goal or involving work in the Technology Area. Individual projects may address more than one MT Goal or Technology Area.

...TIONS PRODUCTION BASE MODERNIZATION AND EXPANSION

In every case, negotiations for a royalty either on a unit or lump sum basis completed the transaction.

Most negotiations stumble over the **degree of protection** which the government can give to the invention/data owner. In most instances, the owner of the data required assurances that the proprietary information would be protected so that it could not be used commercially in competition with his own products. To provide such protection is an **intrinsic part** of the Army program. As of this date no company has accused us of failing to adequately protect its manufacturing technology.

In some instances the government discovers that certain products can be manufactured by **different processes** owned by different companies, and each process is covered by proprietary information not available except under license. A question then arises as to which process the government should use. When there is no indication that one process is clearly superior to others, the acquisition problem is compounded. For example, at least three major chemical companies have different proprietary methods for sulfuric acid regeneration, an operation required at each of the propellant and explosive plants.

Risk Factors to Be Considered

One approach to this situation would be to have a government agency or contractor make an **engineering determination** as to which process is best for ammunition production, considering costs, construction, maintenance, etc. Thereafter, the government would acquire the data rights, perform the architectural and engineering (AE) work, and then complete construction and equipment installation on the basis of the definitive AE technical package. The success of this approach depends on the **accuracy** of the original engineering determination.

Process Engineering Needed

Although new chemical processes may be commercially proven, the existing processes rarely match the identical tonnages or other parameters—for example, meeting the standards that are required as to types and quantities of impurities discharged by a modern ammunition plant. The result is that most chemical processes, even when proven, **require process engineering** for application to the Army's needs.

Standby Not Normal

Cyclical production requirements of munitions interjects at least one additional parameter not normally encountered in designs used in the private sector. There are cases in which industrial designs provide for cost recovery at slackened production rates. But there are virtually no cases where industrial designs emphasize construction materials that will not deteriorate during **extended idle periods** at a plant. Commercial plants are designed for **continuing production**, not for the "be prepared" concept necessitated by defense readiness.

Personal Judgment Vital

The analyst of the competitive processes must learn to **evaluate and distinguish** between the representations made by the "owner of the data" relative to the performance of his particular process and its performance in comparison with competing processes. It is not practical for the evaluator to make a full-scale engineering assessment using pilot plants, risk analysis, etc. It must be noted, too, that an analysis of comparative risks among competing processes is an economic or technical risk in itself.

He therefore must evaluate the data in light of his background and experience; his personal skill is essential to this evaluation process and can sway a decision which has **significant cost implications**.

Deliberations by Methodology

An alternate method of selecting competitive processes is use of the **two-step procurement** process. This process is based on the government's policy of detailing its requirements in terms of performance, capital costs, maintainability, reliability, and other operating costs. All are **key technical and business concerns**.

In Step One, the company's technical proposal is reviewed for adequacy.

In Step Two, the company provides its cost estimates.

The MPBME office assists the contracting agency, which employs an evaluation scheme to compare the bidder's process benefits and related factors with other bids. This **method identifies** the technology offering the greatest benefit to modernization and also defines the contractual risk to be assumed by the parties.

Freedom of Operation Successful

After an award, the successful contractor is given the **widest latitude** in performing the contract. Experience has led the MPBME office to consider the **turnkey contract** as the more preferable instrument for performing modernization using competing processes.

Procedure Reviewed

Where appropriate private data is identified for modernizing the Army's ammunition plants, its **acquisition has been the key** to prosecuting a successful manufacturing technology program. Negotiations for a fair royalty and protection of the **industrial secrecy** of the data have been essential ingredients of the Project Manager's data acquisition plans.

Additionally, several different techniques have been used to ensure that the data represents the best competitive information available. These are **core requirements** when manufacturing technology is to be advanced through data developed by other sources.

Millions To Be Saved

Water Management Big Part of MM&T

Water is a precious and finite resource that can no longer be considered a cheap and abundant commodity. The Munitions Production Base Modernization and Expansion program has found one of its most cost-effective efforts to have been the adoption of new technologies in the processing of water used in Army munitions plants. A water management system based upon **high technology** is to be considered a must in any large-scale industrial undertaking—certainly as valuable in terms of costs as adoption of new high technologies for the actual manufacturing operations.

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Intense public interest in water quality is evidenced by its coverage in the media and by the scope of executive, legislative, and judicial activities devoted to it. Americans can be justifiably proud of the quality of their drinking water and be mildly encouraged by the concerted efforts under way to clean up our waterways. These efforts are consumer or **people oriented**; they are mandatory, not discretional, and are enforceable by law. Most notable is the **Federal Water Pollution Control Act Amendments of 1972**, which specifies a national goal of zero discharge of pollutants from point sources into navigable waters by 1985. The Act provides for effluent limitation **stages** effective in 1977 and 1983.

Waterways' Capacities Near A Critical Level

Industrial manufacturing processes generate significant quantities of waste products—gases, liquids, solids, or any combination. The indiscriminate disposal of wastes almost always results in environmental degradation.

Liquid-borne wastes pose an especially **vexing problem**, since the assimilative capacity of the nation's water resources is approaching a maximum. As industry grows and develops new products, it generates additional quantities of liquid-borne industrial effluents. Many effluents are not fully characterized nor are pollution-abatement methods available to control them to low threshold levels at discharge points or outfalls. For many, the government has **yet to complete** the research necessary to define meaningful standards.

Abatement Control for Six Years

To cope with the problem of adequate water supply, and to lessen possibly harmful effects of discharged effluents from ammunition plants, a **comprehensive project** on pollution-abatement technology has been under way for the past six years under the auspices of the U.S. Army Project Manager for Munitions Production Base Modernization and Expansion (MPBME). This multitask, multiyear project is developing pollution-abatement technologies **specifically applicable** to arsenals and industrial plants manufacturing metal parts, propellants, and explosives and those loading and assembling complete rounds of ammunition—in short, to the complex of facilities comprising the ammunition production base. The program of water management which reduces overall water consumption and minimizes the effluents discharged is fully compatible with stated Army and national objectives.

Water Shortage Not U.S. Obstacle

Since water is a precious resource, its management must be flexible and responsive to demographic and technological change. One-fifth of the world's urban population and three-fourths of the rural population already lack a reasonably reliable source of water. Because world population is **increasing exponentially** and the water supply remains essentially constant, aggressive strategies for conservation and new sources of supply must be developed worldwide.

In the United States, however, impaired human welfare more likely will result from degradation of water quality or inept management than from a physical scarcity of water. Multiple use and reuse of water can be managed only **within natural units** such as a watershed or an entire river basin. Thus, systematic planning and utilization of water resources is effective only when incorporated in a regional plan adopted by a regional governmental entity.

Ideally, this planning quantifies human needs, both group and individual, assesses implications, analyzes current trends, and outlines alternative courses of action to assist decisionmakers in selecting the "best" plan, all factors considered.

Agencies, Activities Abound

Numerous federal agencies engage in water management activities; among them are the Department of Interior; Department of Agriculture; Department of Commerce; Department of Health, Education, and Welfare; Department of Housing and Urban Development; Department of Defense; the U.S. Environmental Protection Agency; U.S. Energy Research and Development Administration; National Science Foundation; Tennessee Valley Authority; and miscellaneous others. Their activities include **enhancement** of water storage, irrigation, waste treatment, sewage systems, pollution control, flood prevention, watershed protection, hydrologic research, water renovation, navigable facilities, power development for desalination, and radioactive waste treatment. The management of water resources on a large area or regional scale can be considered **water resource management** in contrast with the planning and utilization of water at a single facility, which can be considered **industrial water management** or simply water management.

Environmentalists point out that progress in cleaning up the environment is a direct **consequence of statutory** requirements, rather than self-motivated activities by industry in the interest of the common good.

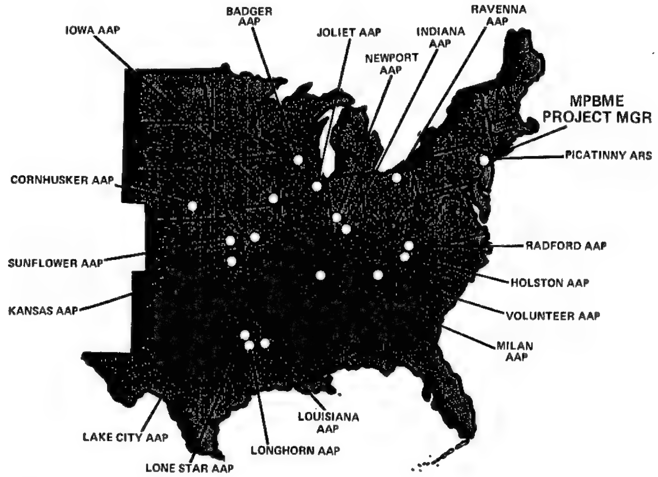


FIGURE 1

AAPs	ACTIVITY					PRODUCT CAPABILITIES																		
	MFG			LAP		ACIDS						EXPLOSIVES								PROPELLANTS				
	ACID	EXPLOSIVES	PROPELLANTS	EXPLOSIVES	PROPELLANTS	ACETIC ANHYDRIDE	GLACIAL ACETIC ACID	CONCENTRATED NITRIC ACID	WEAK NITRIC ACID	CONCENTRATED SULFURIC ACID	OLEUM	DNT	TNT	NG	TETRYL	RDX	HMX	NQ	PRIMERS	NC	SINGLE BASE	MULTIPLE BASE	SOLVENTLESS	COMPOSITE
BADGER	●	●	●					●	●	●	●			●						●	●	●	●	
CORNHUSKER				●																				
HOLSTON	●	●				●	●	●	●							●	●							
IOWA				●															●					
INDIANA	●		●					●	●	●										●	●			
JOLIET	●	●		●				●	●	●	●	●	●		●				●					
KANSAS				●																				
LOUISIANA				●																				
LAKE CITY		●		●															●					
LONGHORN					●																			
LONE STAR				●																				
MILAN				●																				
NEWPORT	●	●						●	●	●			●											
RADFORD	●	●	●					●	●	●	●		●	●						●	●	●	●	●
RAVENNA				●																				
SUNFLOWER								●	●	●								●		●	●	●	●	
VOLUNTEER	●	●						●	●	●	●		●											

TABLE 1

P & E Plants Pose Challenge

"Over the past several years, the federal government has become one of the nation's worst polluters." (Richard M. Nixon, Executive Order 11507, 4 February 1970). Ammunition plants are among these federal polluters, especially those manufacturing propellants and explosives (P&E). Manufacturing **acids as intermediates** and propellants and explosives as end products, the P&E plants resemble heavy chemical process industry both as to types of processes and operations and as to waste streams generated.

The Army's seventeen P&E and Load, Assemble, and Pack (LAP) plants qualify as "worst polluters". Figure 1 indicates their fairly uniform distribution throughout the eastern half of the United States. The Project Manager for MPBME is located at Picatinny Arsenal, Dover, N.J., which also provides the technical coordination of the MPBME program to abate pollution at the Army ammunition plants (AAPs).

"Typical" Plant Atypical

Table 1 is a matrix that categorizes the AAPs as to activity (manufacture or load, assemble and pack) and product capabilities, i.e., intermediates and ingredients used in formulations.

Table 2 lists **munitions unique water pollutants** that result from production at AAPs. Of these pollutants, many are the propellants and explosives; others—like dinitrotoluene (DNT) and hexamine—are intermediates or by-products.

When these pollutants are toxic or otherwise controlled in effluents, monitoring instruments must be available. Since some permissible threshold values are below the sensitivity of available instrumentation, compensating sampling and/or concentration techniques and usable instruments must be developed.

No "typical plant" is representative of all major products and processes since there are **significant variations** in product mix, production volume, effluents, and treatment technology from plant to plant.

Systems Approach Used

The industrial water management system evolved for use at AAPs is a modified version of a systems approach developed by Grumman Research Department in 1969. This systems approach is outlined in Table 3. The Grumman report indicates that industrial waste management is complicated by the diverse technical, economic, and legal considerations of the decision-making process. Thus, a systems approach to the problem such as outlined in the table is usually advisable. The approach must be **tailored specifically** to the particular situation, and it often requires considerable developmental work.

Effluents from P&E plants may be toxic or have other undesirable effects (color, taste, odor); thus, the function of industrial waste water treatment is to **neutralize** these effects prior to reusing or discharging the water.

Many standard treatment processes are available for major effluents in the chemical process industry. Certain

EXPLOSIVES
Nitroglycerin
o-nitrodiphenylamine
1,2-dinitroglycerol
1,3-dinitroglycerol
1-mononitroglycerol
2-mononitroglycerol
Cyclotetramethylene tetranitramine (HMX)
Cyclotetramethylene trinitramine (RDX)
cyclohexanone
hexamine
methylamine
dimethylamine
hexahydro-1,3-dinitro-5-acetyl-S-triamine (TAX)
octahydro-1-acetyl-3,5,7-tranitro-S-tetramine (SEX)
White phosphorus
Nitrocellulose
Tetryl
picric acid
Nitroguanidine
TNT "Pink Water"
2,4,6-trinitrotoluene (TNT)[a b]
2,3-dinitrotoluene (DNT)[a]
2,4-dinotrotoluene[a]
2,5-dinitrotoluene[a]
2,6-dinitrotoluene[a]
3,4-dinitrotoluene[a]
3,5-dinitrotoluene[a]
4-amino, 2,6-dinitrotoluene[a b]
6-amino, 2,4-dinitrotoluene[a b]
o-mononitrotoluene[a]
p-mononitrotoluene[a]
m-mononitrotoluene
1,3,5-trinitrobenzene[a b]
1,3-dinitrobenzene[a]
2,4,6-trinitrobenzonitrate[a]
2,4,6-trinitrobenzaldehyde[a b]
4,6-dinitroanthranile[a b]
n-nitrosomorpholine[a]
2,4,6-trinitrobenzylalcohol[b]
4,6-dinitrol[1,2]benzisoxasole[b]
1,3-dinitrobenzoate[b]
2,4,6-trinitrobenzylaldoxime[b]
3,5-dinitrophanol[b]
PROPELLANT STABILIZERS
Diphenylamine
Dibutylphthalate
PRIMERS
Trinitroresorcinol
Lead styphnate
Tetracene
Pentaerythritol tetranitrate (PETN)
a Found in condensate water.
b Found in LAP water.

TABLE 2

A SYSTEMS APPROACH TO INDUSTRIAL WASTE MANAGEMENT
Problem Definition Survey of water use and waste production Identify and measure pollutants Assess the effects of pollutants on local ecology Define applicable emission standards
Identification of Solutions Design of equipment or process modifications to minimize waste Recovery of waste material and conversion to a useful by-product Treatment of waste water, with or without reuse Adoption of alternative waste disposal methods
Tradeoffs to Consider Compliance with legislated standards Recovery of valuable by-products Gain of community good will Direct and indirect costs Effects on productivity
Program Selection

TABLE 3

oils and greases may be biodegraded using microorganisms; certain acids may be neutralized and the resultant salts separated by evaporation; suspended solids may be removed by mechanical filtration, and the like.

Each AAP must evaluate its **special needs** to determine whether the existing technology suffices or new techniques must be developed.

New Possibilities Considered

Some new techniques being investigated in an MPBME technology applications project to reduce pollutant levels include the following:

- **Freeze technology** to concentrate dissolved solids from waste waters to permit solids recovery
- **Ion-exchange resins** to concentrate and remove nitrates, sulfates, chromates, and phosphates from waste water
- **Reverse osmosis** to perform essentially the same function as ion-exchange resins
- **Biodenitrification** to remove nitrates and nitrobodies from waste water.

No single technology suffices to resolve all industrial pollution problems at any large and complex facility. Each process at each plant must be analyzed systematically and a realistic approach postulated. Since all parameters may not be known and since the use of analytical modeling may not be practical, heuristic or intuitive approaches are often taken. These empirical methods entail rational evaluation of alternative courses of action and the ultimate designation of effective surprise-free approaches.

Three-Phase Program Implemented

The systematic approach evolved for industrial water management is comprised of three study phases, as follows:

- **Phase I—Water Survey**
  Determine quantity and quality of cooling/process water and steam within process (water balances)
- **Phase II—Analysis of Data and Information**
  Recommend recycle/recover/reuse measures based on abatement efficiency, practicability, economics, and energy considerations
- **Phase III—Verification of Applicability to Process via Prototype Testing.**

The MPBME program has conducted studies on over twenty manufacturing processes at AAPs through Phase II.

The **end product** of an industrial water management program is a final plant system water management configuration. As the number of plant processes discharging waste water increases at a facility, the water management program enlarges both in scope and complexity.

The more attractive solutions to plant-scale water pollution are shown in Figure 2. This diagram depicts the results using end-of-process treatment, equipment modification, improved product recovery, reuse, and recycle.

Radford a Keystone Plant

The Radford Army Ammunition Plant, located at Radford, Virginia, is a large P&E facility that manufactures propellants, explosives, intermediates, and other chemical materials as assigned.

Pertinent Statistics—Radford AAP

Area	7100 acres
Hard surface road	156 miles
Standard gauge railroad	31 miles
Security fence	30 miles
Buildings	1214
Covered area	3.4 million sq ft
Personnel	3,000 to 8,200

Utilities Capability

Electricity	580,000 kwhr/day
Filtered water	40 million gallons/day
Raw water	40 million gallons/day
Drinking water	3 million gallons/day
Steam	23.5 million pounds/day

Radford, one of the most versatile plants in the production base, is capable of large-scale production of a **diverse product mix**.

Radford consists of two separate facilities—a manufacturing facility (Radford unit) and a storage facility (New River unit).

Heavy Expenditures Committed

Since Radford is a keystone of the ammunition production base, many projects are placed there. Many of

these provide new or augmented production capabilities; others are devoted to pollution abatement. In total, MPBME projects amounting to more than one-half billion dollars are under way or planned for this facility. Therefore, it is an **excellent candidate** plant at which to examine water management techniques for improving water utilization, abating water pollution, and recovering valuable chemical intermediates.

Nitrocellulose Water Managed Well

In the continuous manufacture of nitrocellulose (NC), wood pulp or cotton linters are continuously nitrated at the rate of 100 to 150 lb/min.

Currently, over 2 million gallons of process water containing about 32,000 pounds of nitric acid are discharged daily. This process water is treated prior to discharge (**neutralization** followed by nitrate removal). In addition, NC fines which collect in the boiling tub and poacher pits must be removed periodically and destroyed (by treatment with aqueous sodium hydroxide).

The manufacturing line **water-control scheme** was devised by the technical staff of Hercules, Inc.—the contractor operator of Radford—under direction of Picatinny Arsenal. Features of this water management scheme include

- **Countercurrent recycling** of neutralized waters (to control buildup of salts from acid neutralization
- **Recycling of recovered water** for blender, poacher, and beater operations
- **Recycling of acidic flume line waters** to a centrifuge and influent stream in countercurrent wash
- **Removal of NC fines** by centrifuging (to permit recovery and reuse of fines and continuous recycling of recovered water).

Studies prerequisite to developing this scheme included

(1) Determination that NC quality was not degraded with increasing acidity of acidic flume-line and centrifuge-recycle waters

(2) Demonstration of efficacy of centrifuging to remove NC fines.

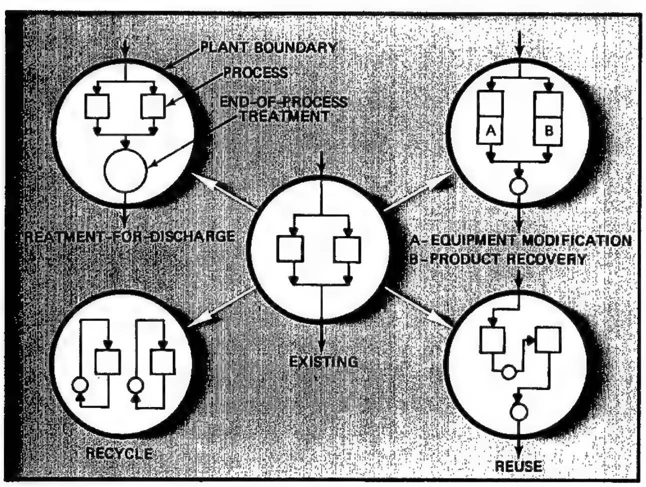


FIGURE 2

The benefits resulting from adopting the proposed scheme are

- Elimination of a neutralization/biodenitrification plant estimated to have cost **$11 million**
- Reduction of filtered water usage by over 1.5 million gallons per day
- Recovery of 32,000 pounds per day of nitric acid
- Virtual elimination of water pollution.

Additional TNT Treatments Proposed

In the manufacture of trinitrotoluene (TNT), nitration is a continuous countercurrent process involving **six stages**. The first stage produces primarily MNT and the second stage primarily DNT. The other four stages convert DNT to TNT.

The waste water discharge to be treated ranges from 47,500 to 57,500 gallons per day per line. The originally proposed and approved abatement facility for the TNT area at Radford was to include neutralization for the acids and carbon adsorption for dissolved nitrobodies.

Proposed water management modifications include

- Eliminating scrubbers in the acid wash and finishing areas
- Recycling water in the area where acid tank cars are washed down and spillage from acid transfer operations occurs
- Recycling cleanup water to sellite and acid washes
- Reducing process water usage
- Changing cleanup procedures.

The proposed modifications will reduce water discharge to about 600 gallons per day per line.

With the water recycle/reuse system, essentially **all process water** from the TNT area is stored and reused in the process, thus eliminating the need for a waste water treatment facility. In place of the waste water treatment facility, some simple plant modifications will be installed (pumps, piping, hold pits). The proposed water management modifications have been approved, and implementation will result in

- **Capital cost savings** of over $1,000,000
- **Operating cost savings** of about $500,000 per year.

Industry Noting Benefits

Industrial water management techniques have achieved **great success** at Army ammunition plants. The development work prerequisite to initiating process changes was conducted under the auspices of the Project Manager for Munitions Production Base Modernization and Expansion.

Measures instituted at Army ammunition plants will not only ensure compliance with the 1977 standard but will also facilitate meeting the 1983 standard and the 1985 goal. Modifications resulting from water management will **reduce plant operating costs** and water usage, and, in some instances, will **reduce energy consumption**.

Water pollution is abated or eliminated by recycling within the same process or reuse in other processes.

Manufacturing costs are reduced by

- Reducing water consumption (and related pumping and treatment operations)
- Reclaiming acids and other contaminants currently discharged
- Reducing hydraulic loadings on downstream abatement facilities
- Eliminating waste water treatment units (e.g., neutralization plants)
- Reducing energy requirements
- Reducing maintenance and labor costs.

Reducing total water requirements for a process gives the Army greater flexibility in **locating new** facilities. More sites may be considered, and the site-location decision may be weighted more on the basis of economics, environment, and other determining factors.

As reported in a recent article in *Business Week*, water management at Army ammunition plants offers a **triple-pronged payoff:**

- Pumps and other mechanical equipment are usually far less costly than conventional water treatment systems
- Energy costs are often slashed
- "Pollutants" can be recycled as raw materials or intermediates.

Industry is looking with great interest at the Army's activities, with an eye toward adopting some of its industrial water management practices for **use in the private sector.**

Acknowledgement: The author is grateful to Arrigo Carotti of Picatinny Arsenal and John C. Thomas of Edgewood Arsenal for their contributions to this article.

Water Management Statutory Background

The statute having the greatest impact on the chemical process industry is the **Federal Water Pollution Control Act Amendments of 1972.** The FWPCA as amended specifies the national goal of achieving zero discharge of pollutants from point sources into navigable waters by 1985.

The well publicized chronology for achievement of improved water quality on a national basis follows.

Title I, Section 10 (a) of the Act establishes an interim goal for the protection and propagation of wildlife and recreation by July 1, 1983.

Title III, Section 301 (b) provides effluent limitations to take effect in two stages for existing nonpublic point discharges:

- Discharges will be reduced by July 1, 1977, through application of "Best Practical Control Technology Currently Available" (BPCTCA).
- Discharges will be further reduced by July 1, 1983, through application of "Best Available Technology Economically Achievable" (BATEA).

Must Look to EPA

The **amendments do not define** these statutory technology levels. The U.S. Environmental Protection Agency (EPA), which is tasked with issuing guidelines, regulations, and standards, must be looked to for further guidance.

The control technology required by **July 1, 1977,** represents the average of the best existing waste treatment performance within each industry category or subcategory.

Where waste treatment performance is generally inadequate, EPA may, in compensation, establish tougher effluent limitations provided that the technology necessary to clean up is available at a reasonable cost.

Effective In-Plant Controls

Most plants may well meet effluent limitations by controlling in-plant technology rather than by building additions to treatment plants. In-plant controls may include conserving water, controlling leaks, purchasing better quality raw materials, substituting chemical additives, or changing manufacturing processes.

The control technology required by **July 1, 1983,** will be based on the very best control and treatment measures that have been developed or are capable of being developed within the appropriate industry category or subcategory.

Furthermore, new plants upon start-up must meet Best Available Demonstrated Control Technology (BADCT).

Title III, Section 304 (b) of the Act requires EPA to establish regulations providing guidelines for effluent limitations to be achieved under Section 301. These regulations are to identify

- Amount of constituents (including thermal)
- Chemical, physical, and biological characteristics of pollutants
- Degree of effluent reduction through application of the two statutory technology levels.

EPA Applies Rationale

The EPA's approach in developing the required guidelines and standards is to

- Categorize each industry
- Characterize the waste resulting from discharges within each industry category and subcategory
- Identify the range of control and treatment technology within each category and subcategory
- Evaluate this technology to determine what constitutes BPCTCA and BATEA.

Title IV, Section 402 of the Act establishes a National Pollutant Discharge Elimination System (NPDES). As legislated, no pollutant can legally be discharged from any point source unless an NPDES permit is obtained from EPA which certifies that the discharge complies with applicable effluent limitations and water quality standards. An important feature of the NPDES permit program requires **dischargers to monitor** their wastes and report the amount and nature of all waste components.

Pure Water by 1985

In recapitulation, the overall goal of the amended Federal Water Pollution Control Act is to eliminate the discharge of pollutants ("zero discharge") by 1985 and, as an intermediate goal, to achieve **high-quality water by 1983** and eliminate the discharge of toxic pollutants (harmful substances in dangerous quantities). To achieve the Act's objectives by the dates set will require a monumental national effort.

Brief Status Reports

NEW TECHNOLOGY IN SMALL CALIBER AMMUNITION MANUFACTURING. The process utilizes hi-speed rotary presses to fabricate the cases, bullets, and primed cases for the 5.56mm ammunition, which are then automatically assembled and 100% inspected and packed. The prototype system has demonstrated rates of 900 parts per minute. The entire process is integrated by an automated material handling system and controlled by minicomputers. Production Quality Control System monitors production and maintains production data. For additional information, contact Brij Rai, 201-328-4086 or AUTOVON 880-4086.

COMPUTER CONTROL APPLICATIONS TO CONTINUOUS TNT MANUFACTURE. This project designed and installed equipment for regulating the operation of a continuous TNT manufacturing line by remote digital control. This includes field instruments and valves, a digital computer with associated electronic equipment, operating panel, closed-circuit TV, and operator controls. This control system will regulate the operation of the line through start-ups and shutdowns and will optimize the running of the line. For additional information, contact Andrew Keyes, 201-328-6751 or AUTOVON 880-6751.

AUTOMATED LINE FOR MELT POUR PROCESSING OF HIGH EXPLOSIVES. The purpose of this program is to conduct a pilot plant evaluation for the modernization of the melt/load facility in the areas of explosive handling, melting, pouring, casting and cooling, etc. This modernized mass production line will eliminate or reduce undesirable features of conventional batch melt/pour lines, including large explosive volume operation, personnel exposure to high hazard operations, high manufacturing costs, high capital investment, and high explosive concentration per bay or building. Included in the design of this new process is automated computer control, remote operation of the hazardous processes, continuous process equipment such as conveyors, variable speed feeders, explosive pumps, automated multiple pouring, and controlled cooling. For additional information, contact Mr. Larry Pasterick, (201) 328-4071 or AUTOVON 880-4071.

INERTIA WELDING. The inertia welding process utilizes the kinetic energy stored in a revolving flywheel-spindle system, converting stored energy to frictional heat; enough heat to soften, but not melt, contacted points of the rotating band and a thin-walled projectile by thrusting one part against the other. This process is currently estimated to be four times faster than the overlay process, requires less copper, decreases power consumption and reduces inspection cost. Savings of $2.01 per shell are projected for an annual savings of $2,894,400, based on projection rate of 120,000 shells/month. For additional information, contact Mr. Yut Wong, (201) 328-3458 or AUTOVON 880-3458.

SINTERED STEEL PREFORMS FOR FRAGMENTING SHELL BODIES. This project was undertaken to develop a process for forming 81mm mortar shell metal parts from powdered metal (P/M). The process developed comprises a method of using P/M of AISI 1040 composition to successfully make this item. The P/M was first compacted in a hydraulic press, then compacted hot in another press after sintering at proper temperature to a density of 99% of rolled steel. The sintered preforms were then cold extruded to form "near net shape" mortar shell bodies ready for finish machining. Ballistic tests have indicated that the process is successful. For additional information, contact Mr. Frank Zaleski, (215) 831-6425 or AUTOVON 348-6425.

WHITE PHOSPHORUS DRY FILL. A safer, cleaner, and less expensive white phosphorous loading method has been developed. White phosphorous has always been a difficult material to load into munitions. It burns in the presence of air, releasing a heavy white smoke and a persistent flame, and it also produces large quantities of contaminated water. Workers must use protective clothing such as face shields and aprons for safety and health reasons. A new method known as "dry fill" calls for loading the shell in a totally enclosed system which has been charged with an inert gas atmosphere. Results obtained from operation tests were outstanding. Benefits derived include a 95% reduction in air and water pollution, a reduction in operation man-hours, a 25% production increase in 105mm M60 smoke rounds, and safer and cleaner working conditions for line operators. For additional information, contact Mr. Stan Payne, (201) 328-6791 or AUTOVON 880-6791.

AUTOMATED BAG LOADING, CHARGE ASSEMBLY, AND PACKOUT. The totally automated equipment to load, assemble, and package the base-ignited propellant charges for the 155mm and 8-inch howitzers is in the final debugging stages. The system will take empty cloth bags and bulk propellant and turn them into completely assembled and packaged charges at a design rate of 20 per minute. Approximately twenty-one tons of propellant per hour is processed through the bulk fill scales, which must be accurate enough to maintain a tolerance equal to 0.1% of the increment weight, or 48 grains on a pound-size increment. The entire

system is controlled by a main console which uses miniprocessors to control the various modules and maintain a balanced flow of product through the automated conveyor network. With the integration of numerous inspection stations, the production from this line will possess more uniformity and be more reproducible than was previously possible from the hand line. For additional information, contact Mr. Dick Koppenaal, (201) 328-6791 or AUTOVON 880-6791.

RECOVERY OF HEAT FROM PROCESS WASTE WATERS. Recovery of heat wasted by industrial processes is now a matter of primary concern because of the national energy crisis. Several plant operations auxiliary to propellant manufacture have liquid effluent streams containing substantial quantities of heat wasted to the environment. These conditions contribute to thermal pollution and significant waste of thermal energy. One heat recovery system of interest is an industrial-sized heat pump which picks up heat from an available source, augments the heat with additional heat from a refrigerant expansion-compression cycle, and transfers the resultant total heat to input process waters. The heat pump system is comprised of a two-stage, hermetic centrifugal compressor complete with lubrication system, control panel, interstage equipment, shell and tube source fluid color (evaporator), insulated heat exchanger and delivery water heater (condenser) and a refrigerant charge of R-114 (Freon) working fluid. Other heat transfer systems will also be investigated. For additional information, contact Mr. W. Heidelberger, (201) 328-4076 or AUTOVON 880-4076.

SEPARATION OF FINE EXPLOSIVES FROM ACID WATER SLURRIES. The Army has been investigating ways of continuously filtering fine explosives from acid water slurries, because current methodology of batch filtration is inefficient due to extremely long filtration times. Present horizontal belt filters cannot withstand concentrated hot acetic acid that is found in the manufacture of HMX. The rubber support belt deteriorates quickly in this type of harsh environment, creating a short operating life for the support belt. Recent laboratory studies indicate that a support belt made of flourosilicone rubber may possess a greater resistance to hot acetic acid, so appropriate evaluation is being conducted. Bird-Pannevis, however, has recently introduced to North America a new horizontal vacuum filter that does not require a support belt. This essentially eliminates the problems of deterioration where rubber or other elastomers are attacked by acid. For additional information, contact Mr. A. Hartman, (201) 382-2497 or AUTOVON 880-2497.

FINE EDGE BLANKING FINE TUNES PRODUCTION COSTS. The existing process for drilling, reaming, and polishing (or burnishing) small holes in fuze and timer components is labor intensive, expensive, and time consuming. Therefore, two new technology approaches were considered—high speed stamping and fine edge blanking. After evaluating both approaches, fine edge blanking proved to be the optimum choice, resulting in a 20 to 30% reduction in unit cost by eliminating many secondary operations. For additional information, contact Herbert Gerson, (201) 328-4081 or AUTOVON 880-4081.

INTERCONNECTION OF FLUIDIC CIRCUITS. This operation presents a serious problem in the design of fluidic circuits in munitions fuzing, timing devices, and control systems. The problem of joining discrete circuit components is compounded by the need for accurate alignment, leak-free connection of matched channels between components, and channels consistently having less than 10% total variation in channel impedance due to the inclusion of joining material or other contaminants. Fluxless vacuum brazing has met with some success in joining the circuit components. The technique utilizes a thin metal shim with a ternary alloy deposited on both sides as the brazing material. Refinement of this technique will reduce unit costs, reduce production lead time by employing off-the-shelf components in various logic sequences, and permit the wider application of CAD/CAM concepts to the design and fabrication of fluidic circuits. For additional information, contact Robert Hamilton, (301) 394-3090 or AUTOVON 290-3090.

COMPUTER MONITOR AND PROCESS CONTROL FOR ARTILLERY SHELL BAND WELDING PROCESS. Under a contract placed by Frankford Arsenal, a prototype computer-controlled gas metal arc (GMA) welder has been developed for the application of nonferrous rotating bands on artillery projectiles. Using closed loop control, a minicomputer monitors and controls such parameters as projectile rotational speed, torch oscillation frequency and amplitude, arc voltage, welding current, and electrode wire and cold-wire feed speed. A reduction in band welding time has been obtained from approximately 5 minutes per projectile to 3 minutes per projectile. For additional information, contact Mr. Eugene Kelley, (215) 831-7119 or AUTOVON 348-7119.

MONITORING OF TOXIC EFFLUENTS WITH BIOLOGICAL SENSORS. The standard techniques to monitor emissions and effluents generated from manufacturing operations are by the use of sophisticated-instruments hardware. Often, the translation of this data from the instruments to the actual effects the pollutants have on the environment is difficult or inapplicable. Using live biological sensors to monitor the ambient environment solves some of the translation problems. In biosensors, the actual aquatic and botanical lives can be measured to establish baseline data. Special parameters are identified and recorded (e.g., measuring the breathing rate of fish or coring trees to establish growth rate). Once the biosensors are set up, data can be gathered and compared with the baseline data. Response times have been realistic and practical. For additional information, contact Mr. K. Wong, (201) 328-4076 or AUTOVON 880-4076.

First MM&T Effort

MICOM Picked As Promising Area

A Dubuque, Iowa, native who entered the Army as a private, MAJOR GENERAL GEORGE E. TURNMEYER became Commander of the U.S. Army Missile Command and Redstone Arsenal in October, 1975. He has been at Redstone Arsenal since April 1973, first as Project Manager for the Lance missile system as it moved from development into operational use with American soldiers in the United States and overseas, later as MICOM's Deputy Commander, a position he held when selected for promotion to two star rank. The general heads an organization of 8,500 civilian and military personnel managing research, development, production and support of Army rockets, missiles and related equipment throughout the world. Designated a Logistician by the Department of the Army, the general has spent much of his career in that military specialty which involves providing and maintaining in operational condition, the American soldier's weapons, equipment, and supplies. He received his Bachelor of Military Science degree from the University of Maryland in 1954 and his Master of Business Administration in Industrial Management from Babson College in 1957. General Turnmeyer has attended several Army Ordnance schools, the Armed Forces Staff College, and the Industrial College of the Armed Forces. He has served in the Logistics branch of the Deputy Chief of Staff and taken special logistics courses at Ft. Lee, Virginia. He also has commanded a battalion of the 7th Infantry Division in the field in Korea.

At the Missile Command we see manufacturing technology as a key to high return on investment in both current and future Army missile and rocket systems.

Heretofore, there had been little emphasis on missile manufacturing technology and only a few projects conducted. Those consisted of projects for specific manufacturing needs but they were not part of a coordinated approach or program.

No Incentives for Contractors

In part, this came from a belief that manufacturing technology and production techniques were the concern of our contractors only. They had, in the past, come up with improved techniques, processes, and equipment to the mutual benefit of the Army and the individual contractor. The incentive for the contractor to invest in improvements in this vital, but often neglected area, was not strong. The possibility that he would be unable to obtain a return on his investment because of selection of a competitive/alternate source or because government procurement policies would not allow payoff of capital investment within the contract performance period further diminished the incentive to pursue manufacturing technology.

It became apparent that additional emphasis and incentives were required from the government customer if a major effort was desired from industry to improve manufacturing technology.

A directive from William P. Clements, Jr., Deputy Secretary of Defense, charged each of the services to increase manufacturing technology emphasis and to substantially increase funding support for it beginning in FY 77. Another directive to the service secretaries in April 1975 gave additional guidance. He told the services to centralize management of their manufacturing technology programs and to study several major systems to identify applications of new manufacturing technology that would reduce costs. Mr. Clements said that additional funding will be requested from Congress if needed to get manufacturing technology projects under way fast.

Under the direction of MG Harry A. Griffith, then Director, Directorate for Research, Development and Engineering, DARCOM assumed responsibility for central management of the Army's activities.

A DARCOM study of planned materiel procurements thru 1981 pinpointed missiles as the most promising area for manufacturing technology application. As a result, MICOM got the opportunity to pilot the first effort of the DARCOM response to the Deputy Secretary of Defense directive.

Panel of Experts Identify Areas

Assisted by the Army Materials and Mechanics Research Center, we decided to kick off our program with a conference of experts from industry and government to identify the missile systems areas where manufacturing technology improvements could yield most significant cost reductions and attendant return on investment.

Dr. John L. McDaniel, the Director of the Missile Research, Development, and Engineering Laboratory where our program was placed, invited industry leaders to chair panels charged to give comprehensive technical and cost data on missile systems and suggested manufacturing technology projects. The panel chairmen and their areas included

- Justin Margolskee, V.P. & General Manager, Raytheon Company—Guidance
- Dr. Leonard F. Buchanan, V.P. & General Manager, General Dynamics—Control
- Dr. David Altman, Vice President, Chemical Systems Division, United Technologies—Propulsion
- Elliot Ring, Chief Engineer, Orlando Division, Martin Marietta Corporation—Structures
- William L. Shepard, Vice President, Advanced Programs, LTV Aerospace—Launchers

- Joe Moquin, President, Teledyne Brown Engineering—Containers
- Dr. William B. Simecka, Vice President, Tactical Systems, Northrop Corporation—Test Equipment.

General Griffith, conference director, was supported by Dr. McDaniel and his staff in the missile technical areas and by Dr. Al Gorum and his staff from AMMRC in planning and conducting the conference.

Cost Drivers the Target

The panel chairmen recruited speakers and potential manufacturing technology projects. Members of each panel were required to present papers on either a specific missile system or a specific manufacturing technology project, with potential application. Further, the papers were required to identify the cost drivers in the missile system area of the panel. These cost drivers not only addressed a set of standard components defined for each panel, but manufacturing cost categories such as material, purchased parts, fabrication and processing, as well.

A potential manufacturing project submission required salient points in each of several areas: missile system applicability, manufacturing problem, proposed solution, project cost and duration, benefits, and assumptions.

Three specific conference aims were addressed:

(1) Identification and analysis of the major cost drivers in the production of Army missile systems

(2) Definition of projects providing new or improved manufacturing technology

(3) Assessment of the potential payback from those projects if implemented.

When technical and economic assessment had been done, panel chairmen compiled all potential projects submitted at the conference, a listing that totalled 360 projects valued at about $140 million.

Panel chairmen concluded that there were significant potential payoffs to the Army thru emphasis on missile manufacturing technology, although only about $6 million of the Army's annual $60 million budget for manufacturing technology was being spent on missile manufacturing improvements. Their recommendations were that the Army actively pursue a coordinated program in missile manufacturing technology and put more money in it.

Ten Projects Picked Out

After the conference, MICOM specialists tackled the massive quantity of technical and economic data. Based on their assessment, it was apparent that a number of projects should be begun as quickly as possible. DARCOM ultimately approved ten projects for late start in FY 76. They include

- Semi-additive/thin foil processes for the fabrication of printed circuit boards
- High speed machining of aluminum
- Extrudable HTPB propellant
- Methodology for producing low cost/disposable mandrels
- Production methods for producing squeeze castings
- Computerized production process planning
- Screening of electronic components
- Mounting of nonaxial lead components
- Handling of hybrid chips via a tape carrier lead frame.
- Low-cost strip laminate motor cases.

These ten projects, costing a total of $2.5 million, offer potential savings of about $65.5 million in the production of missile systems since they attack several major cost drivers. These projects will be aggressively pursued by MICOM manufacturing technology specialists.

Categories Established

Also, as a result of the conference, all the 360 projects were combined for evaluation and the following manufacturing technology areas established:

- Production Planning and Management
- Electronics/Electrical
- Metals
- Nonmetals
- Propellant
- System Design
- Specifications and Standards.

In each of these areas, subheadings were established to better categorize each project submitted. For example, Production Planning and Management had subgroupings for manufacturing systems analysis and energy conservation. A detailed assessment was then made considering system(s) needs and production schedules, technical merit, cost, project duration, and the potential return on investment; then a priority was placed on each project. The essential data and information required to establish a viable five-year plan were then available. Much more detailed information is available in the Missile Manufacturing Technology Conference Report, which provides comprehensive coverage of conference activities, projects, assessment, and recommendations.

MICOM intends to have the most productive manufacturing technology program possible. The conference got us off to a running start, but it is important that we continue to assess our manufacturing technology needs in light of changes in missile system requirements, technology, and schedules.

Not a Flash in the Pan

Our view is that emphasis on manufacturing technology is not a flash in the pan, but a viable and necessary tool for achieving production cost targets. MICOM will fully support these programs and their future development.

In planning the impending division of MICOM into the U.S. Army Missile Research and Development Command (MIRADCOM) and the U.S. Army Missile Materiel Readiness Command (MIRCOM) which will be co-located at Redstone Arsenal, we have fixed total management of the manufacturing technology programs for both MIRCOM and MIRADCOM in the Advanced Systems Development and Manufacturing Technology Directorate of MIRADCOM.

Lead Time Critical

'73 War Brings Armor Speedup

The outcome of the Middle East conflict of 1973 resulted in a need to rapidly expand the production base for armored combat vehicles. Unfortunately, increasing the production rate to accomplish this was handicapped by the lack of capability to produce critical components due to the long lead times required. This disadvantage was felt mainly in the **casting industry** and other labor intensive areas.

To be responsive to the critical need for reducing lead times, the MM&T Program at TARADCOM is being directed toward such efforts as

- Automated fabrication processes
- Improved environment for welders to increase their productivity
- Utilization of computer techniques to improve the casting process.

Initially, these casting processes will be applicable only to small components. Subsequently, the developed technology can be expanded to include the larger components.

Of equal importance to the production processes is the **need for reducing the costs** of manufacturing combat vehicles. A Combat Vehicle Manufacturing Technology (MT) Conference held in October had the goal of making the MM&T Program more responsive to this need. In preparation for this conference, an intensive effort was undertaken with the aid of industry to identify manufacturing shortcomings and cost drivers. At the conference, the combat vehicle manufacturing industry provided proposals to improve manufacturing processes and reduce costs.

Conference Charts Guidelines

The direction of the Tank-Automotive MM&T Program for the next five years is expected to be charted from inputs received at the MT conference. Resources for the program will be expended in viable manufacturing technology projects. The areas where maximum return on our invested dollars can be realized is difficult to ascertain, since the building of combat vehicles depends on a large number of suppliers and purchased parts.

The **identification of cost drivers** is of paramount importance. Data provided by several vehicle and component manufacturers has been analyzed to provide a meaningful picture of high cost problem areas and areas of opportunity.

MAJOR GENERAL OSCAR C. DECKER, JR., assumed command on July 1 of the U.S. Army Tank-Automotive Research and Development Command, Warren, Michigan—a newly established facility. General Decker previously had served as Deputy Commander and as Director of Procurement and Production at the U.S. Army Tank-Automotive Command. A native Nebraskan, he began his Army service in 1943 as an enlisted man in Armor. When he was discharged in 1946, he returned to the University of Nebraska, where he graduated in 1951 with a degree in Business Administration. After commissioning in the Ordnance Corps he was detailed to the Armor Branch, where he served with the 2nd Armored Division in Europe. Following this tour of duty, he attended the Ordnance Advanced Course and the Command and General Staff Course. He later received a Master's Degree in International Affairs from George Washington University. General Decker has served as a Battalion Commander both in Europe and Vietnam; as Project Manager, Armored Reconnaissance Scout Vehicle; and as Executive Assistant to the Assistant Secretary of the Army (Installations and Logistics).

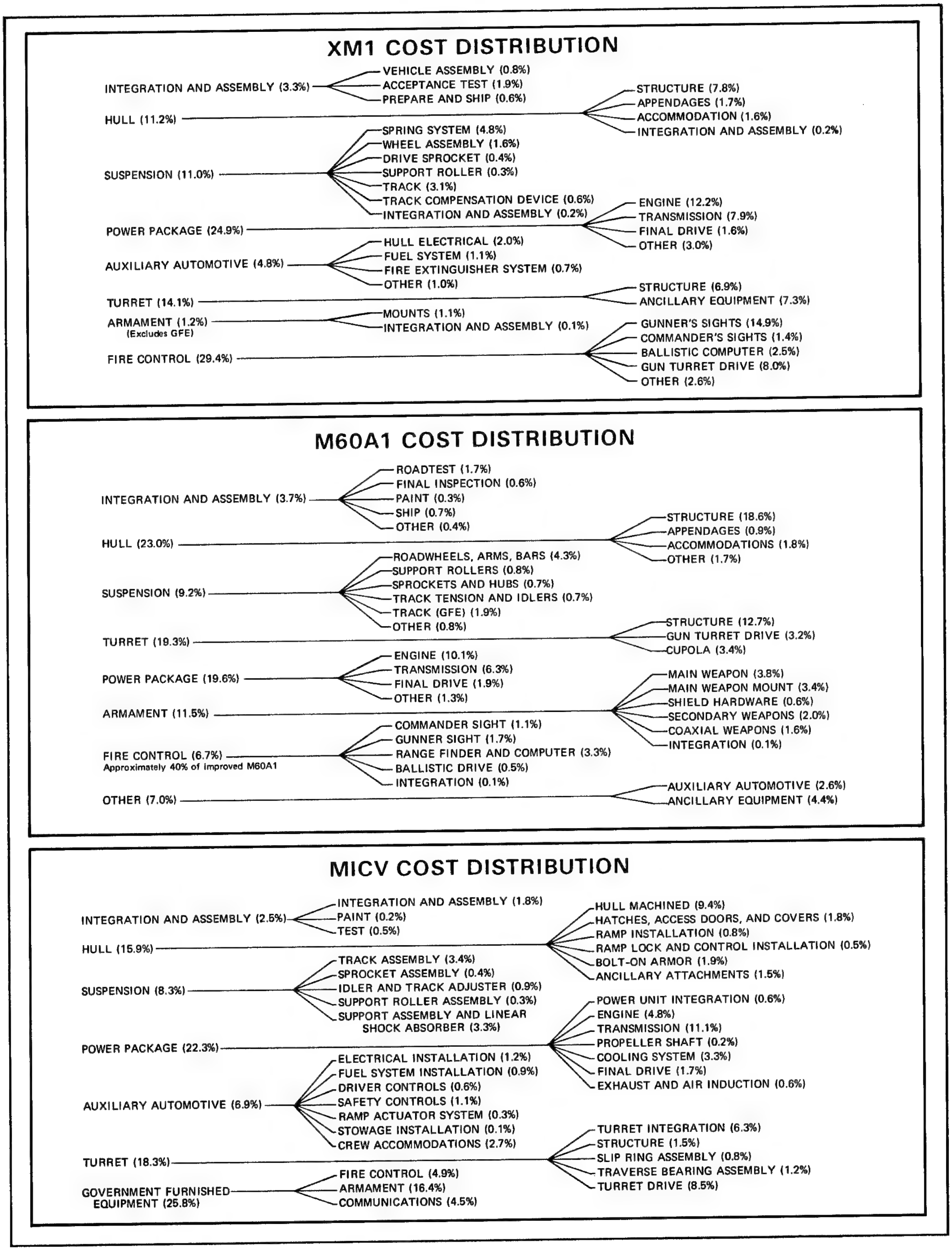

XM1 COST DISTRIBUTION
INTEGRATION AND ASSEMBLY (3.3%)
VEHICLE ASSEMBLY (0.8%)
ACCEPTANCE TEST (1.9%)
PREPARE AND SHIP (0.6%)
HULL (11.2%)
STRUCTURE (7.8%)
APPENDAGES (1.7%)
ACCOMMODATION (1.6%)
INTEGRATION AND ASSEMBLY (0.2%)
SUSPENSION (11.0%)
SPRING SYSTEM (4.8%)
WHEEL ASSEMBLY (1.6%)
DRIVE SPROCKET (0.4%)
SUPPORT ROLLER (0.3%)
TRACK (3.1%)
TRACK COMPENSATION DEVICE (0.6%)
INTEGRATION AND ASSEMBLY (0.2%)
POWER PACKAGE (24.9%)
ENGINE (12.2%)
TRANSMISSION (7.9%)
FINAL DRIVE (1.6%)
OTHER (3.0%)
AUXILIARY AUTOMOTIVE (4.8%)
HULL ELECTRICAL (2.0%)
FUEL SYSTEM (1.1%)
FIRE EXTINGUISHER SYSTEM (0.7%)
OTHER (1.0%)
TURRET (14.1%)
STRUCTURE (6.9%)
ANCILLARY EQUIPMENT (7.3%)
ARMAMENT (1.2%)
(Excludes GFE)
MOUNTS (1.1%)
INTEGRATION AND ASSEMBLY (0.1%)
FIRE CONTROL (29.4%)
GUNNER'S SIGHTS (14.9%)
COMMANDER'S SIGHTS (1.4%)
BALLISTIC COMPUTER (2.5%)
GUN TURRET DRIVE (8.0%)
OTHER (2.6%)
M60A1 COST DISTRIBUTION
INTEGRATION AND ASSEMBLY (3.7%)
ROADTEST (1.7%)
FINAL INSPECTION (0.6%)
PAINT (0.3%)
SHIP (0.7%)
OTHER (0.4%)
HULL (23.0%)
STRUCTURE (18.6%)
APPENDAGES (0.9%)
ACCOMMODATIONS (1.8%)
OTHER (1.7%)
SUSPENSION (9.2%)
ROADWHEELS, ARMS, BARS (4.3%)
SUPPORT ROLLERS (0.8%)
SPROCKETS AND HUBS (0.7%)
TRACK TENSION AND IDLERS (0.7%)
TRACK (GFE) (1.9%)
OTHER (0.8%)
TURRET (19.3%)
STRUCTURE (12.7%)
GUN TURRET DRIVE (3.2%)
CUPOLA (3.4%)
POWER PACKAGE (19.6%)
ENGINE (10.1%)
TRANSMISSION (6.3%)
FINAL DRIVE (1.9%)
OTHER (1.3%)
ARMAMENT (11.5%)
MAIN WEAPON (3.8%)
MAIN WEAPON MOUNT (3.4%)
SHIELD HARDWARE (0.6%)
SECONDARY WEAPONS (2.0%)
COAXIAL WEAPONS (1.6%)
INTEGRATION (0.1%)
FIRE CONTROL (6.7%)
Approximately 40% of improved M60A1
COMMANDER SIGHT (1.1%)
GUNNER SIGHT (1.7%)
RANGE FINDER AND COMPUTER (3.3%)
BALLISTIC DRIVE (0.5%)
INTEGRATION (0.1%)
OTHER (7.0%)
AUXILIARY AUTOMOTIVE (2.6%)
ANCILLARY EQUIPMENT (4.4%)
MICV COST DISTRIBUTION
INTEGRATION AND ASSEMBLY (2.5%)
INTEGRATION AND ASSEMBLY (1.8%)
PAINT (0.2%)
TEST (0.5%)
HULL (15.9%)
HULL MACHINED (9.4%)
HATCHES, ACCESS DOORS, AND COVERS (1.8%)
RAMP INSTALLATION (0.8%)
RAMP LOCK AND CONTROL INSTALLATION (0.5%)
BOLT-ON ARMOR (1.9%)
ANCILLARY ATTACHMENTS (1.5%)
SUSPENSION (8.3%)
TRACK ASSEMBLY (3.4%)
SPROCKET ASSEMBLY (0.4%)
IDLER AND TRACK ADJUSTER (0.9%)
SUPPORT ROLLER ASSEMBLY (0.3%)
SUPPORT ASSEMBLY AND LINEAR SHOCK ABSORBER (3.3%)
POWER PACKAGE (22.3%)
POWER UNIT INTEGRATION (0.6%)
ENGINE (4.8%)
TRANSMISSION (11.1%)
PROPELLER SHAFT (0.2%)
COOLING SYSTEM (3.3%)
FINAL DRIVE (1.7%)
EXHAUST AND AIR INDUCTION (0.6%)
AUXILIARY AUTOMOTIVE (6.9%)
ELECTRICAL INSTALLATION (1.2%)
FUEL SYSTEM INSTALLATION (0.9%)
DRIVER CONTROLS (0.6%)
SAFETY CONTROLS (1.1%)
RAMP ACTUATOR SYSTEM (0.3%)
STOWAGE INSTALLATION (0.1%)
CREW ACCOMMODATIONS (2.7%)
TURRET (18.3%)
TURRET INTEGRATION (6.3%)
STRUCTURE (1.5%)
SLIP RING ASSEMBLY (0.8%)
TRAVERSE BEARING ASSEMBLY (1.2%)
TURRET DRIVE (8.5%)
GOVERNMENT FURNISHED EQUIPMENT (25.8%)
FIRE CONTROL (4.9%)
ARMAMENT (16.4%)
COMMUNICATIONS (4.5%)

FIGURE 1

While 45 different materials have been identified, as well as 120 different manufacturing processes, only a few materials and processes represent the major investment areas.

Examples of cost distribution for the XM1, the M60A1, and the MICV are shown in Figure 1. From an overview, 79 parts alone represent a planned average Discounted Anticipated Investment(DAI) of more than $4.9 million per part through the time frame considered. Further analysis, shown in Figure 2, indicates that 51 of these 79 parts have both a significant material cost and a significant fabrication cost.

In addition to the specific parts analysis, an attempt has been made to identify major technology areas. The data in Table 1 shows the number of and planned investment for those parts which involve the various materials and processes indicated. Any one part, along with the dollars to be invested, could be included in more than one set of figures if the part is subjected to multiple processing. Those materials and processes which represent high investment areas are identified. This data highlights the **major cost areas** and the associated technologies and suggests where the best potentials are for manufacturing technology investment.

The SPIDERCHART (Figure 3) shows the percent of planned investment (DAI) in each of the component areas. This information indicates that each of these component areas plays a significant role in future Army expenditures for tracked combat vehicles.

Small Parts Not Overlooked

Several facts are evident. In the first place, although a majority of the initial procurement costs, less fire control and armament costs, are in the hull and turret, over the long run considerable investment is made in each of the other component areas. This warrants extensive review of manufacturing technology opportunities in each of the component areas. Furthermore, it is obvious that volume considerations are much more important in dealing with spare parts. This, then, suggests that opportunities may also be available for good return on investment in projects dealing with low unit cost, high unit volume parts production. Examples of these parts are components such as

- track shoes
- road wheels
- engine cylinders
- crankshafts
- sprockets
- starters
- regulators
- generators
- batteries.

Goals for combat equipment must be both performance and cost oriented. One way to meet these objectives is through the improvement and development of fabrication processes which will provide know-how for practical production of those materials emerging from the laboratory.

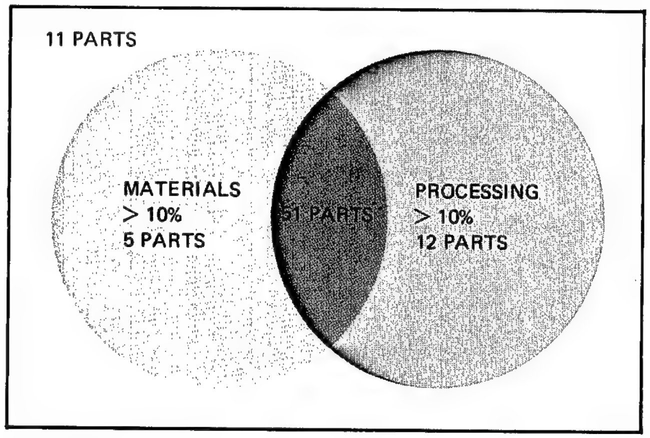


FIGURE 2

Cast Preforms Forged

An example of such an effort is our manufacturing method project for forging cast armor preforms. This process combines the advantages of casting and forging processes by producing a large armored tank hull section in two steps. In the first step (Figure 4), a hull section, such as the front nose, is cast into the approximate shape of the finished item. In the second step, the cast preform (8″ wide and 30″ deep) is forged at a hydraulic press to finished dimensions, undergoing a two-to-one metal reduction which results in an 8′ wide and 60″ deep section (Figure 5). This section is suitable for attaching to other hull sections. For the same ballistic protection, this 10,000-pound forged hull front would be some 800 pounds lighter than a similar item made as a casting. If sufficient quantities are involved to permit amortization of basic die costs, the process affords a high rate production method of manufacturing large armor components with **better ballistic protection** or equal ballistic protection at reduced weight. Processing advantages being demonstrated in this project can be made applicable to product improvement of any large armor casting. They can also be applied to any large armor subcomponent contemplated in future vehicles.

Manufacturing cost reductions normally can be obtained if labor intensive operations can be eliminated or minimized. Projects which will demonstrate the feasibility in automating the fabrication processes are being pursued. The automated process, with its attendant computer control, provides greater reproducibility and consistency of operation. In many areas, the computer control processes can be more flexible in a shorter response time.

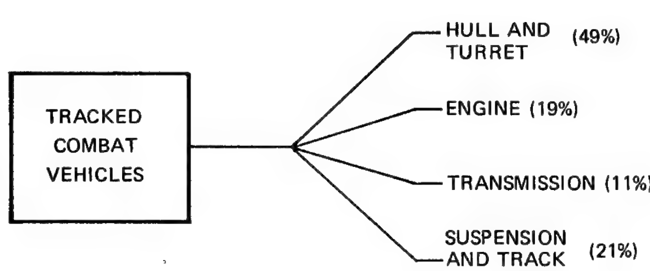


FIGURE 3

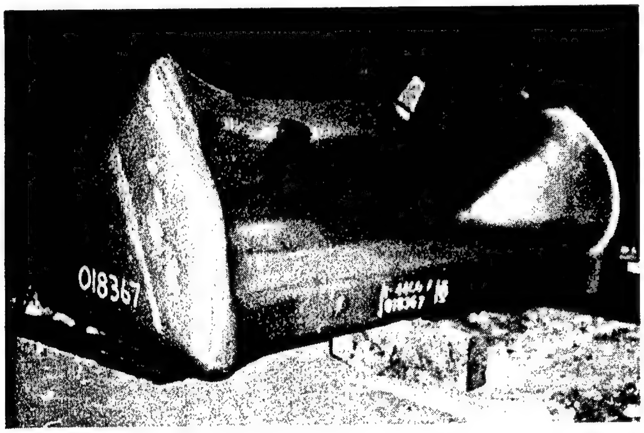


FIGURE 4

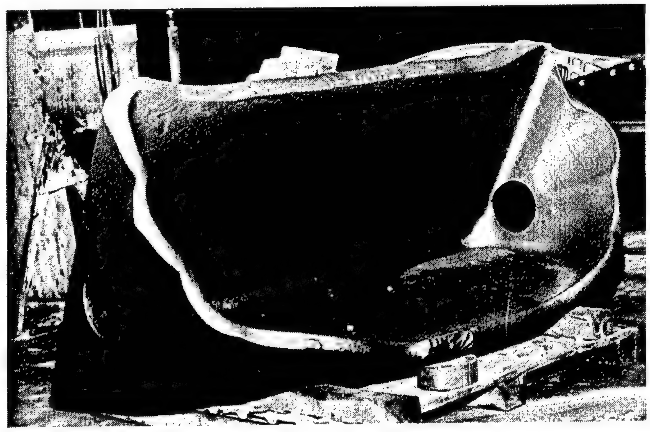


FIGURE 5

Welding Processes Computerized

An example of tank-automotive interest in the Computer Aided Manufacturing (CAM) projects is the fabrication of armored vehicles utilizing the **electron beam welding** process. In this project, the feasibility of joining aluminum armored vehicles by means of the electron beam welding process is being demonstrated. This process offers unique capability in the fabrication of thick aluminum armor. It also offers a single pass welding capability due to the high penetration associated with the beam. Present electron beam welding requires a vacuum chamber. Facilities which would be required to fabricate vehicles are shown in Figure 6. A comparison of weld joints as joined by electron beam and the conventional metal arc inert gas welding method is shown in Figure 7. The electron beam welding results in a very small heat affected zone which **improves the ballistic properties** at or near the weld.

Comparable efforts are also directed toward welding of steel hull structures by automating the gas metal arc welding process. The present production method used in fabricating ferrous (steel) vehicles utilizes manual stick electrodes. This method emits intense heat plus smoke, which contributes to welder fatigue. The heat resistant clothing worn by welders also takes a toll on their efficiency. The **automated welding process** will reduce the required number of welders as well as eliminate manual discomfort and reduce the relative time-consuming operation.

A subscale system was set up to determine necessary control and program configuration. An automated system will permit anticipation of problems which, when corrected, will result in sound weld metal. Use of automated systems will improve economy and productivity and also the quality of combat vehicles. Automated welding of a vehicle such as the M60 tank can **increase the welding rate** twofold; i.e., from approximately two feet per hour to four feet per hour for a finished weld.

Advances in the state of equipment of the technology indicate that, in the near future, joining of combat vehicles could be performed by **laser beam welding** and/or electron beam welding, which will not require a vacuum. Use of these methods, either singly or in combination, may result in the most economical, efficient, and ballistically acceptable weld joint.

Computer Aided Design Used

Two other projects have been undertaken in the CAM area. One that is currently being worked is computer aided design and manufacturing for forging of track shoes. The other program is the improved foundry casting process utilizing computer aided fluid flow and thermal analysis.

The **forging program** is being directed towards designing forging dies by a methodology which eliminates the empirical approaches. Considerable scrap losses (forging flash), unexpected die wear and breakage, and the cost of forging dies represent a sizable portion of the manufacturing costs for track shoes and connectors. Manufacturing costs can be reduced by obtaining closer tolerances, thereby reducing machining allowances and scrap losses by eliminating or minimizing flash. Optimized die design will increase the life of the forging dies. Flash losses represent approximately 20% of the materials for the T130 track used on the M113A1 Armored Personnel Carrier.

The **casting process** is a highly adaptable method—not so in many competing processes—for producing complex shapes in many alloys. However, the casting process is highly inefficient in its usage of raw materials and energy. About 50% more material is required than exists in the final configuration. The inefficiency of the process results in a cost penalty. The use of a computer to apply advanced fluid flow and thermal analysis to the casting process would result in a more efficient utilization of present casting facilities. A project is being initiated to take advantage of these computer capabilities. This technology will be carried out through an interactive design tool that simulates the casting process. Simulating the mold filling process will allow consideration of more alternate locations and sizes of gates and risers. Casting defects can be anticipated; thus, preventive measures can be taken in designing the molds and patterns.

Completion of the program will result in less direct cost of castings through a **reduction in scrap losses** and an increase in yield. An additional benefit will be that the **quality could be guaranteed**, which may permit a reduction in casting weight for a specific application.

Powder Metallurgy Saves

Programs are directed to develop or adapt new improved manufacturing technologies, with the objectives of reducing manufacturing costs and developing alternate production methods to increase the production base on improved vehicle components. One approach in attaining these objectives is in the powdered metal (PM) area. The PM forged process was first utilized for Army parts in the manufacture of high performance gun components by ARMCOM. The program demonstrated that the PM **forged components** could be produced with fatigue and impact strengths comparable to wrought materials at a significantly lower cost.

At TARADCOM, a powdered metallurgy effort was directed toward fabricating two types of vehicular components; i.e., the **gears** used in the differential of the M151A2 ¼-ton truck and the **pistons** used in the hydraulic wheel brake cylinders of the 1¼, 2½, and 5-ton trucks. The gear work was to demonstrate the feasibility of using lower cost forged powdered metallurgy gears in a critical, highly loaded application. Successful application of these critical Army automotive gears could provide the impetus to adapt the PM process to other highly loaded automotive parts.

Program effort was to determine the most economical powders and fabrication techniques to **produce a successful gear**. Two approaches for fabrication of gears were undertaken: the gear and shaft pressed

(1) as one integral component

(2) as a powdered metal gear with a wrought bar shaft welded to the gear (Figure 8).

Forging trials on the gear preform showed that a density of 99.9% of theoretical was obtained at 40 tons per square inch pressure and a specimen temperature of 2200 F (1210 C).

The primary cost advantage of the PM forging process for producing differential gears over the conventional process lies in **better material utilization** and a significant **reduction of machining operations**. Cost reductions of 23% were projected for PM gears which require some machining and 35% for PM gears which require no machining. Gears were installed on an M151A2 vehicle differential and tested at Yuma Proving Grounds, Yuma, Arizona. The test requirement for payloads, towed loads, and speeds were in accordance with the vehicle specifications. All PM gears completed testing satisfactorily.

The other application of powdered metallurgy in the current military vehicle is for the production of **pistons for brake cylinders**. The brake system contains several dissimilar metals which promote galvanic chemical action. Under normal field usage, moisture penetrates the brake system or fluids oxidize, causing corrosion inside the brake cylinder. The present military brake system contains aluminum in contact with a gray iron cylinder housing.

Replacement of the aluminum piston by a sintered iron piston reduces this corrosion action. **Sintered iron pistons** were made from iron powder with a small quantity of babbit. Density is controlled to approximately 2% porosity. Pores are impregnated with an inhibited synthetic preservative lubricant of the polyoxyglycol type which lubricates as well as increases corrosion protection. It is compatible with conventional brake fluids.

Tests were conducted on 2½ and 5-ton trucks to compare the performance of the sintered iron piston with the aluminum piston. Each vehicle ran a total of 10,000 miles, plus the Jennerstown mountain brake test course and the saltwater environmental test at Virginia Beach. In all cases, aluminum pistons were corroded and gummed. The sintered iron pistons **withstood the environment** in both applications without undue wear or corrosion.

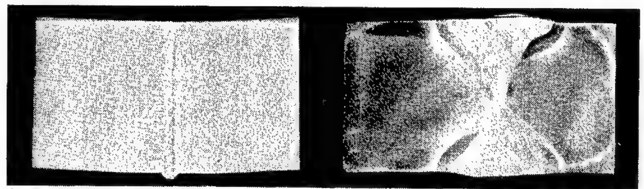
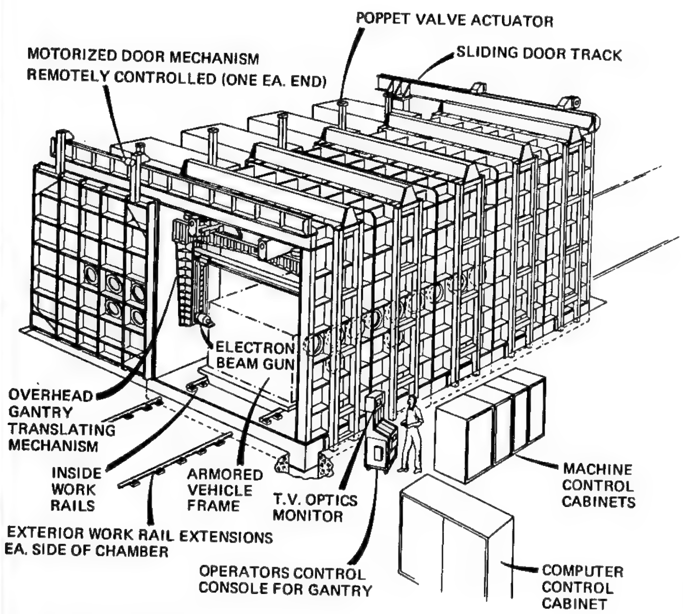

ELECTRON BEAM WELD METAL INERT GAS WELD

FIGURE 7



OVERALL INTERIOR CHAMBER DIMENSIONS

LENGTH	384"
WIDTH	158"
HEIGHT	178"

FIGURE 6

Dual Hardness Armor Fabricated

TARADCOM continually seeks to employ special materials for its vehicles to defeat specific threats. These

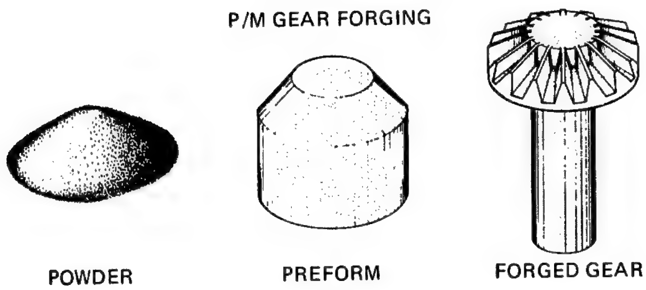


FIGURE 8

materials usually require fabrication techniques which are unique. For example, dual hardness armor was considered in certain vehicular design. This composite armor consists of different chemistry and hardness on each side of the plate. It is, in effect, **two plates of different characteristics** bonded into a single plate. Since this armor is of such a high hardness level—Rc 60 on one side and Rc 50 on the other—special welding procedures were required. Dual hardness armor was used to fabricate a pilot hull to determine its feasibility for use in large structures. Figure 9 shows the completed hull. This hull was tested on a "shaker" type test stand to locate the presence of weak areas. Vibration tests and stresses induced by the shaker test did not reveal weld joint weaknesses. This test verifies that dual hardness material is an **acceptable constructional steel for armor** hull combat vehicles.

Weight Saved by Joining

Weight saving to increase vehicle performance is a prime consideration. A method to reduce weight in combat vehicles is to use more than one type of material in the fabrication, taking advantage of their most desirable properties. **Welding dissimilar materials** such as aluminum and steel requires special fabrication methods, so a project was directed toward using various dissimilar materials for combat vehicle construction. Joining such materials as steel and aluminum or steel and titanium was found to require special transition strips. Techniques were developed in which fracture occurred in the expected lower strength weld and/or heat affected zone. A test specimen of this type of failure is shown in Figure 10. This project has demonstrated the feasibility of utilizing more than one type of metal in weld construction of combat vehicles.

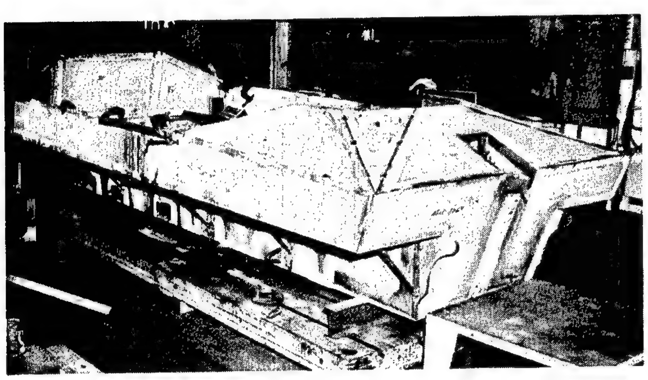


FIGURE 9

High Hardness Armor on Horizon

A recent innovation in the steel industry is the development of **electroslag refined steel (ESR)**. This steel is made with very low impurities at reasonable cost. TARADCOM and other agencies are exploiting the use of ESR steels for armor. Ongoing development is expected to provide weight savings and/or improvements in ballistic protection up to 20%.

Because of its high purity level, it is possible to heat treat this steel to very high hardnesses of about **500 Brinell** and use it at this level for armor. Normal armor materials would be in the 250–300 Brinell range. In addition, the carbon content levels of ESR armor are higher than standard armor. These factors improve ballistic performance dramatically but cause **difficult welding** problems, requiring use of refined, closely controlled procedures for successful vehicle fabrication. The objectives of this program are to explore variables and develop suitable weld processes that will ensure reliable welding practices on a production basis for all types of contractors.

Successful completion of this program is essential to the application of ESR armor for combat vehicle application. Without the availability of fully defined weld procedures, application of ESR armor will not be realized or, at best, its usage will be delayed in vehicle production. Development of the procedures will provide a reliable welding process that can be utilized in combat vehicle construction.

Weight Reduced with Aluminum

There are many tank-automotive components that could be fabricated from aluminum to reduce weight if it were not for the inherently poor wear resistance of aluminum. With this in view, **a weld-deposited, hard-face aluminum coating** was developed. As a candidate component using this coating, an aluminum version of the steel T-142 track shoe for the M60A1 tank was also developed. The track block was made of aluminum, but its center guide, end connectors, pad and pins remained the same as the steel track. The hard coating was applied to the wearing edges of the track block. The track shoes were vehicle tested at Aberdeen Proving Ground to determine their endurance and performance characteristics. The aluminum track successfully completed 8,545 miles of endurance testing. The use of aluminum instead of steel reduces the T-142 track weight-per-pitch length from 76.6 to 59.9 pounds, which compares favorably with the 61.3-pound weight of the T97 track. On an experimental basis, the steel wear ring on the M60 roadwheel in addition to the track was successfully replaced with the hard coating. This effected a 12% weight saving. These limited **tests verified the fabrication feasibility**. Further testing is required to ensure maximum reliability in service.

Less Metal Removed

The tubes for tube-over-torsion bar suspension

springs require large amounts of metal removal by machining. Fabrication techniques are being developed to decrease machining of the tube by inertia welding the spline ends or upsetting the spline ends at the time the bar spring is being fabricated. Either of these methods should result in a substantial cost reduction of this component.

Nonmetallics See New Technique

In the area of nonmetallics, **"in-place" casting of polyurethane** in the track show roadwheel side cavity and curing with minimum heat was successfully developed. The project determined the optimum fabrication technique for production. A pilot line was built which was designed to cast the polyurethane roadwheel pads at a rate of 120 per hour. This line was shipped to Red River Army Depot for inclusion in their track rebuild program and is currently being installed there. This program will increase the production base by allowing fabrication of the roadwheel path elastomers at facilities other than those of the rubber industry.

Tougher Batteries Coming

Battery container breakage is a major cause of premature failure. To rectify this problem, techniques are being developed to fabricate low maintenance batteries with high impact plastic areas. This will result in a significant reduction in battery replacements.

New Tests Developed

In conjunction with establishing improved manufacturing technology, the MM&T Program addresses the attendant quality assurance requirements. To ensure greater reliability of tank-automotive componentry, a nondestructive method to determine the amount of residual stresses in a given configuration was developed. This information can be determined on-line since the stress determination is continuous and rapid. This method will detect any changes in processing which might result in unfavorable stress distribution.

Projects have also been conducted to set up radiographic standards for weld joints. These standards are for both full and partial penetration welds.

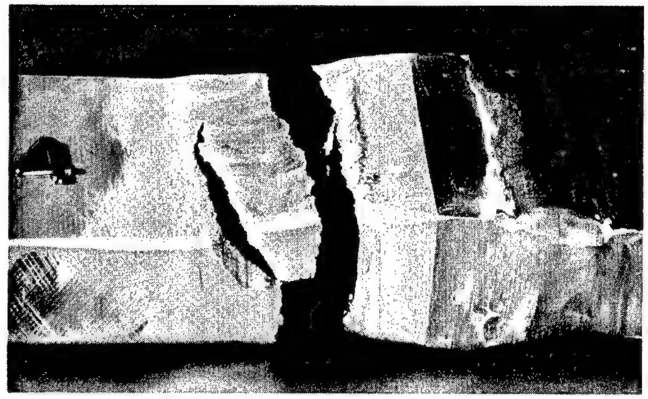


FIGURE 10

Automated ultrasonic methods are also being developed for use in determining soundness in tank components, as well as in tires. Both methods will result in rapid, more economical ways of ensuring quality in Army materials.

Processes Implemented Sooner

Our MM&T Program is being made more viable by **inclusion of industry** in our planning stages. This was initiated by the MT Conference. Participation of industry in our MT Program will allow introduction of newly developed processes at earlier dates. The added emphasis by DARCOM and DA ensures availability of sufficient resources to successfully carry out our Program objectives. This program includes

- Automation
- Material handling
- Improved quality control
- Repeatability of production processes
- Fast feedback of information in case of field failures due to defective manufacture.

Throughout all these efforts, increased emphasis will continue to be placed on cost reduction and the conservation of material, energy, and personnel resources.

TARADCOM and TARCOM MM&T efforts will continue to provide maximum manufacturing engineering support to the production base for procurement of tanks, trucks, and other military ground vehicles. Rapidly emerging technologies, long lead times, large capital requirements for facilities, and ever changing international circumstances present constant and complex challenges. To meet these challenges, our MM&T Program seeks to establish and implement the latest and most advanced practical techniques and processes.

PROCESS AREA	MATERIALS USED											
	STEEL		ALUMINUM		OTHER METALS		PLASTICS		ELASTOMERS		COMPOSITES	
	QTY	$$	QTY	$$	QTY	$$	QTY	$$	QTY	$$	QTY	$$
Machining	101	879.0	66	436.9	–	–	–	–	–	—	–	–
Welding	23	574.5	41	313.3	4	66.5	–	–	–	–	2	8.0
Forging	32	362.7	14	184.0	4	87.0	–	–	–	–	–	–
Casting	37	432.9	32	213.7	2	32.2	–	–	–	–	–	–
Surface Treatment	26	143.8	19	176.3	4	64.0	–	–	–	–	–	–
Mechanical Joining	90	304.3	16	105.7	8	77.0	2	205.0	2	4.0	2	10.6
Thermomechanical Treatment	21	138.8	8	8.0	3	60.6	–	–	–	–	–	–
Extrusion	9	34.6	3	33.9	1	26.9	2	5.7	–	–	–	–
Molding	–	–	–	–	–	–	1	3.8	6	19.9	–	–
Soldering	–	–	–	–	3	5.3	–	–	–	–	–	–

QTY – Number of parts considered $$ – Dollar cost of parts involved (in millions)

TABLE 1

Wide Impact Felt

ECOM Program Began Early

MAJOR GENERAL ALBERT B. CRAWFORD, JR., assumed command of the Army Electronics Command in August 1975, after serving as Project Manager, Army Tactical Data Systems. A graduate of West Point, General Crawford holds a B.S. degree in Military Science and an M.S. in Electrical and Industrial Engineering. In addition to Signal Corps schools, he is a graduate of the Command and General Staff College, the Defense Weapons Systems Management Course, and the U.S. Army War College. He also has attended several intensive courses in computer sciences and information technology and has lectured on these and related topics before professional societies and at Army schools. General Crawford has served as Chief, Information Sciences Group and Deputy Director, Management Information Systems Directorate, Office of the Assistant Vice Chief of Staff; as Commander, 12th Signal Group; as Chief, Communications Systems Engineering and Management Agency; Chief of Systems Integration and TACFIRE Project; and in numerous other responsible positions in the Signal Corps.

The manufacturing base programs ECOM has sponsored over the past twenty-five years have affected the lives of nearly all Americans, and also many citizens of foreign countries. The electronics equipment in everyone's homes today can be directly traced to roots in these production programs. The large-scale production of the transistors, semiconductor diodes, thyratrons, and other solid state components of the fifties; the micromodule assembly techniques and laser production of the sixties; and more recently the development of large base production of automatic testing units—these have brought all types of electronic appliances within reach of the average citizen. Latest developments in lasers and fiber optics may indicate another threshold for large-scale production of a whole new range of useful civilian items.

The Manufacturing Methods and Technology program in the Electronics Command began some twenty-five years ago. At that time the group that performed this function consisted of approximately thirty engineers with supporting personnel. It was a division of the Industrial Preparedness Activity which was located in Philadelphia, PA, and reported to the Procurement and Distribution Branch of the Office of the Chief Signal Officer, Washington, D.C.

At that time, these efforts were called Industrial Preparedness Measures (later changed to Production Engineering Measures) and were directed at the establishment of adequate sources, including geographic dispersion, for production of critical components and materials needed to support the communication-electronics mission of the Army under mobilization conditions.

Staff Now Reduced

At the present time, the MM&T function is performed by the Production Processes Section, consisting of six electronic engineers, within the Procurement and Production Directorate (see organizational structure—Figure 1). It can be contacted by addressing correspondence to the attention of DRSEL-PP-I-PI-1 or by telephone, Autovon 99-24993. This section initiates, justifies, assists in placement, and technically administers the entire MM&T program in the command.

These responsibilities require an extensive technological background in electronic components and systems manufacturing processes, procurement practices, and contract administration procedures. Many of these engineers have in excess of 20 years of experience managing MM&T projects. The current major thrust of these projects is to establish improved and/or new production processes and techniques that are not employed in the present industrial base but are required for the production of Army Communication-Electronic equipment.

Work Covers Broad Range

In the Electronics Command, the current MM&T work effort may relate to any material, process, and/or technique applicable to one or more of the following technical disciplines:

- Integrated circuits (microwave, thick and thin films)
- Test equipments
- Optics (display, night vision, lenses, fiber optics)

- Power sources (batteries, crystals)
- Passive components (resistors, capacitors, transformers)
- Active components (tubes, transistors, diodes, thyristors, detectors)
- Materials (silicon, gallium arsenide, mercury-cadmium-telluride, glass)
- Assembly processes
- Computer-aided processes
- Miscellaneous.

A few examples of projects are attached as Exhibits 1 to 3 to illustrate the type of MM&T effort performed by ECOM. The narrative briefly describes the processes and techniques that will be improved, the types of communications-electronics equipment that will benefit from these improvements, and the benefits (cost savings or otherwise) that will accrue from these projects.

Emphasize Reduced Costs

The MM&T program at ECOM is now one of the major activities diligently pursued to reduce the high cost of electronic equipment. Essentially, all of the current and planned MM&T efforts and expenditures are justified on their need and potential for achieving cost reductions.

The work load (if we use funding and number of projects as indicators) has increased considerably in the past few years. It was fairly stable—usually, about 3 to 6 million dollars per year—up to FY-75. For example, the FY-75 program comprised 13 projects for $6.0 million. In FY-76 it rose to 18 projects funded at $10.5 million. The FY-77 program is 22 projects totaling $11.2 million and the FY-78 program is expected to be of a similar magnitude.

Future years should show an increase in the funding and scope of the MM&T program in ECOM in view of the recent emphasis placed by DOD on effecting equipment cost reductions by improvements in manufacturing technology.

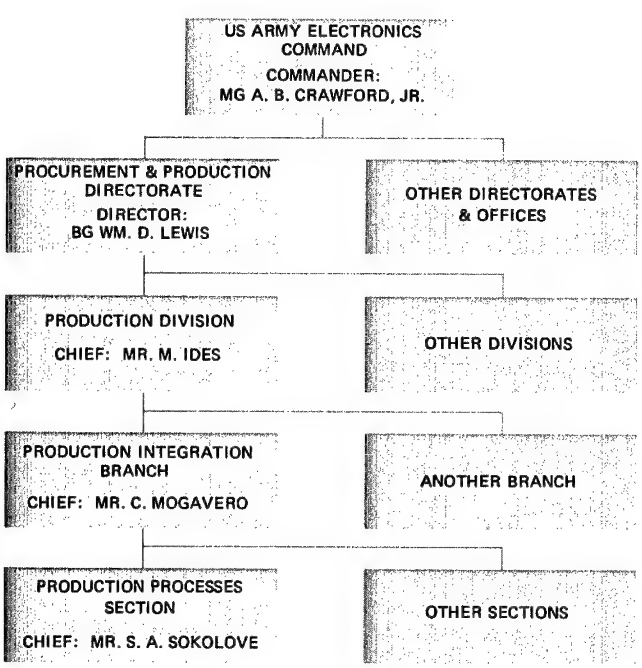


FIGURE 1

Exhibit 1 Electronic Quality Assurance Test Equipment (EQUATE)

Background

The receipt of a large volume of defective equipment at depots during the late 1960's prompted General Wolwine, AMC, to question the acceptance procedure utilized in the acquisition of electronic equipment. The task of altering the cited techniques was assigned to ECOM. The answer derived was in the form of a two-stage approach—a short range solution and a long range answer. The long range answer was EQUATE.

The EQUATE was to be comprised of a computer controlled automatic test system which would perform acceptance tests on a wide variety of circuits, assemblies, and systems. In addition to running test programs automatically, it would generate, edit, and validate test programs. The system was to be designed for use by the engineer, technician, or company that might be inexperienced in computer programming.

Program Purpose

The purpose of the program was to prevent acceptance of questionable equipment and to improve the confidence in and quality of accepted electronics material by utilizing the latest technique in the field of AUTOMATIC TEST EQUIPMENT (ATE). These techniques would revert to basic mathematical techniques in lieu of adding additional measuring circuitry and metering.

Solution

The long range answer was programmed as part of the MM&T function—namely, to reduce the cost of manufacturing and improve the quality of electronic equipment. As part of its MM&T function in 1970, the Production Division conceived a method for final test and inspection which would reduce the cost of testing and improve its effectiveness and reliability, yet not be restricted to specific operational ranges. This method would utilize automatic techniques and be based on mathematical procedures that are alterable by changes in the control software. These changes would be accomplished on line, using keyboard inputs and technical English. This approach is now referred to as Third Generation ATE, which results in a highly reliable system in which duplication or redundancy of hardware is eliminated. This approach is expandable to other areas such as optics and engines.

Operation

The computer is used to control the generation of test waveforms for the Unit Under Test (UUT) and to analyze the UUT response. Waveform generation is accomplished by storing (or computing) the digital representation of the desired signal, placing this signal into a high speed memory, and then outputting this memory to a high-speed Digital to Analog Converter (DACON). In this manner, both standard (sinusoid, square wave, ramp) and nonstandard (telemetry, radar, etc.) waveforms may be generated by one general purpose device.

The computer is also used to perform UUT waveform analysis. The general technique is to reduce the UUT responses to digital quantities through high speed Analog to Digital Converter (ADCONS). These digital quantities are then operated on with selected algorithms to yield the appropriate parameter of interest. Some of the parameters measured by EQUATE are amplitude modulation (am), frequency modulation (fm), spectrum analysis, distortion analysis, and peak voltage measurement. The measurement of all operational characteristics can be accomplished for both digital and analog circuits, plus phase sensitive measurements that span the spectrum from low frequency servo analysis to high frequency complex impedance. The technique is not frequency limited.

Results

A contract was awarded in FY 1970 to RCA, Burlington, MA, to implement the techniques and construct an operational model. This contract was completed ahead of schedule. Since the model showed the capabilities of the technique, use of the system was requested by the Electronic Component Laboratories. This request was granted and the equipment was loaned to aid in the program for Automatic Test Support Systems (ATSS), the successor to Computer Aided Test Equipment (CATE).

The model was trailer mounted and shown at various locations throughout the country using fielded hardware such as the AN/PRC-77, AN/ARC-115, and TD-352 as samples of defective equipment. It was then taken to Fort Hood, Texas for evaluation under field conditions. This test was operated by enlisted personnel of varying skill levels, with a resulting availability of 95 to 98 percent.

A similar system was purchased by the Navy for operation at their Indianapolis facility; it has performed for better than 2500 hours with only one half hour of downtime. The system also will be used to support the Advanced Army Helicopter System, and it has been expanded for use in the optics area by the recently completed Automatic Image Device Evaluation (AIDE) project.

A command decision has been made to use the model to support the TACFIRE System, so it will be deployed to Europe. Therefore, it will not be available for industrial use. Additional systems are being procured by the Air Force for AWACS and by ECOM for ASA and NSA to support their electronic warfare systems and secure communication requirements. An additional model is being procured for depot operation.

Exhibit 2
MM&T—For the Automatic Processing of Multialkali Photocathodes

This project established techniques for producing multialkali photocathodes used in first and second generation intensifier tubes by automated process. These photocathodes are required in the production of image intensifier tubes. These tubes are used in Night Vision equipments for viewing under low light level conditions.

Two concurrent programs were conducted: internal and external processing. In the internal approach, the photocathode is processed in the tube envelope with the source of alkali and antimony remaining in the tube or in external appendages. In the external approach, the photocathode is processed in a separate port section of the vacuum system and then transferred to the tube body and sealed. The dual approach was necessary due to the differences in the processing techniques for first and second generation image intensifier tubes.

Modeled from Human Skill

The basic requirements for the automated control were derived by fully instrumenting and recording each step in the photocathode processing by an experienced operator. This data was then correlated with the final cathode response, and techniques used for the highest yield cathode served as controls for the automated cathode processing systems. The process control program and control system can be made accurate and reproducible, as it is not affected by the human problem of fatigue, indecision, slow reflexes, and misjudgment.

This effort supported the current night vision programs including the Night Vision Sight Individual Served Weapon, AN/PVS-4, Night Vision Sight Crew Served Weapon, AN/TVS-5, and future night vision direct view programs that will be directly affected by the techniques established. Both programs were successfully completed.

As a result, the repeatability of the process, the yield, and photoresponse spread of cathode fabrication were significantly improved. This increase in yield and quality of the photocathodes also improved the Government's procurement position in that the intensifier tubes are now fabricated with better and more uniform performance, at less cost, and with a shorter production lead time.

$900,000 Saved

A substantial savings of monies—approximately $900,000—was estimated to be realized in the first two years after completion for the AN/PVS-4 and AN/TVS-5 programs alone. Additional application of image devices should result in further savings.

The results of these programs have been encouraging as regards the viability of the automated alkali photocathode deposition process. Experience now indicates that this technique is entirely suitable for production use, and the technology and expertise developed in conjunction with these programs should make the transition from the prototype systems to the production units a smooth one.

Presently, the automation of the multialkali photocathode processing is being incorporated by NI-TEC, Inc. (one of the contractors) into their production line in the fabrication of the second generation inverter (internal processing) tubes.

Exhibit 3
MM&T—Integrated Circuit Fabrication Using Electron Beam Technology

Purpose

The overall purpose of this program is to implement electron beam writing technology for the fabrication of microcircuits without the use of masks. The elimination of the mask and the masking process will reduce the most significant source of pattern defects during integrated circuit fabrication. Electron beam direct slice printing will permit greater circuit design complexity and will lead to lower device costs because of the increased yield. Present day yields are less than 10 percent. The implementation of this program is expected to produce a yield of 20 percent and increase the availability of bipolar integrated circuits (Bipolar Transitor Logic) of complexity greater than 100 bits.

This MM&T effort was awarded to Texas Instruments on 1 July 1976 and is expected to be completed by 1 July 1978.

The program will be divided into three tasks.

- **Task A** will demonstrate yield improvement with the direct E-beam technique, utilizing existing equipment and existing electron resists. Processes will be developed and refined for the oxide layer and the Molybdenum-Gold (Mo-Au) definition.
- **Task B** will demonstrate decreased cycle time by the implementation of high speed electron resist. The present electron resist (polymethymethacrylate—PMMR) has a high resolution but requires a large exposure dose, and its adhesion properties are not as good as some photoresists, e.g., Kodak Metal Etch Resist (KMER). In order to develop an electron resist process for high density complex integrated circuits, the following steps will be characterized and developed: (1) exposure characteristics of the electron resists; (2) adhesion to the specific surfaces involved in making the device; and (3) etch resistance with both wet and dry processes.
- **Task C** will demonstrate shorter cycle periods by the automation of the beam diameter control and the material (wafers) handling. Parameters will be defined for the "outline and fill" approach using the capability to switch back and forth between a large (4 to 5 micrometers) and small (1 micrometer) beam. It is estimated that this "outline and fill" approach would achieve a reduction to one-quarter of the cycle time. The automatic slice loading system will reduce the cycle time by three minutes.

The R&D has been performed by private industry. This program will enable the industry to produce complex bipolar integrated circuits at the rate of 10,000 per month, and the 256 bit Random Access Memory (RAM) will be used to demonstrate this production capability.

Objective/Benefits

The completion of this project will make available a viable technique for the volume production of high density, high frequency integrated circuits. The 256 bit RAM presently has a price structure of $36; the application of E-beam technology should reduce the price to $15.

Items Supported

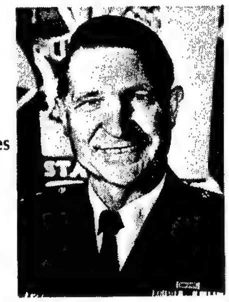
The TRI-TAC System and the Vandal Secure Communication will use high density C-MOS devices whose cost and yield could be improved by using the E-beam approach. PATRIOT (formerly SAM-D) needs a high speed 300 gate array which is costly when using current techniques. Volume production utilizing the E-beam approach could reduce costs considerably.

Additional Benefits

- Surface wave devices are presently being fabricated both by the photolithographic process and E-beam technique. For those devices operating above 1GHz, the use of the E-beam approach is mandatory to be cost effective. The application of the production improvements developed by this project should reduce the cost of these devices by approximately 40 percent.
- The generation of a photo mask by the conventional photolithographic process takes 24 hours per layer and costs $600. Using the E-beam approach in combination with the high speed electron resist developed in this program, the price will be $400 per layer and the time period will be reduced to one hour.

Aero Technology Exchange Begins

$43,000,000 Savings Forecast



MAJOR GENERAL EIVIND H. JOHANSEN took command of the US Army Aviation Systems Command in August 1975 after serving three years as Director of Supply, Headquarters, US Army Materiel Command. He previously had advised on the redeployment of US forces from Vietnam and on Vietnam logistics in his capacities as Chief of the Supply Distribution Division and Deputy Chief of Staff for Logistics at the Pentagon. A native of South Carolina, he enlisted in the Army shortly after graduating from high school and served as an enlisted man in the Infantry and Ordnance Corps. He later returned to civilian life and graduated from Texas A&M as an honor student, active in athletics and student affairs. Later, as director of a special Quartermaster task force that analyzed integrated management in the military services, he participated in development of the DoD concept for integrated management under the Defense Supply Agency. General Johansen has completed several of the Army's special officer training schools and has attended graduate schools at Harvard and George Washington University, receiving his M.S. in International Affairs at GWU in 1968.

The new MM&T Program sponsored by the Army Aviation Systems Command will overcome the effects of **two long-standing shortcomings** of Army aviation contracting—small production orders that do not support heavy investment in production engineering and also the contractor practice of keeping one's most competitively advantageous methods to one's self. In so doing, the technology transfer program will produce savings expected to total $43.5 million from thirty-four projects costing $14.5 million. This amounts to a **3-to-1 ratio** of savings versus investment. All this from a wider application of the latest manufacturing know-how.

The demand for higher performance has always been one of the main driving forces in the development of new weapons systems. However, in recent years the trend toward reducing the Defense share of the Federal budget has added a new challenge—that of reducing acquisition and life-cycle costs while meeting the required performance objectives. One important means for meeting this challenge is through the development of advanced manufacturing technology and its application to the production of military hardware.

For Army aviation this function is performed by the Manufacturing Methods and Technology (MM&T) Program under the direction of the Army Aviation Systems Command (AVSCOM) in St. Louis, Missouri. This article describes the primary objectives of AVSCOM's MM&T Program as well as the organization for managing the program at AVSCOM. Examples of some current MM&T projects are presented to show the type of work presently being done. Finally, some of the more promising areas for application of advanced manufacturing technology to production of Army aircraft are discussed and an indication given as to the direction of future AVSCOM MM&T projects.

Return on Investment Basis for Selection

Management of the AVSCOM MM&T Program is performed by the Production Technology Branch within the Directorate for Research, Development and Engineering. This branch coordinates project suggestions received from

private industry and various government research laboratories with projects developed in-house in order to develop an overall MM&T program.

The projects selected for inclusion in the program are those which offer the best return on investment and are usually aimed at reducing manufacturing costs, improving reliability and maintainability, ensuring that production-ready equipment and tooling is available at the time of production buys, and/or implementing the results of promising contractor developed efforts. The important aspect of these projects is that they have a definite application to production of current or future Army aircraft. This assures the Army that it will receive the benefits of reduced acquisition and life-cycle costs.

Government Researchers Advise

Most of the project work to develop new manufacturing technology is done by private airframe and engine contractors under contract to AVSCOM. However, AVSCOM also makes use of the expertise available at various government research organizations such as the Army Materials and Mechanics Research Center at Watertown, Massachusetts, and the Army Air Mobility Research and Development Laboratory, which has directorates at various locations around the country. These laboratories assist AVSCOM by submitting project suggestions within their own areas of expertise and also by using funds received from AVSCOM to contract directly to private industry for MM&T project work.

Currently, there are approximately thirty-four active projects being performed under AVSCOM sponsorship with total funding of near $14.5 million. The anticipated savings from these MM&T projects are estimated at approximately $43.5 million. These projects are concerned with the advancement of manufacturing technology in a wide range from casting and forging to the development of automated processes to fabricate components from composite materials.

Incentive Lack Confronted

Prior to the establishment of a formal Manufacturing Methods and Technology Program at AVSCOM, the major airframe and engine contractors producing hardware for the Army were relied upon to develop and apply new manufacturing techniques mainly through their own internally funded efforts. This approach, however, contained definite shortcomings as far as benefits to the Army were concerned.

In the first place, there was often little incentive towards independent development of advanced manufacturing technology where there were few civilian markets, if any, for its application. The relatively low production quantities involved with a military procurement often made it difficult to recoup investment costs and still keep the price of the hardware competitive. Even in those instances in which private industry did develop advanced technologies on its own, these developments seldom coincided with major Army hardware development programs, so maximum benefit to the Army was not realized.

And, as might be expected, major advances in manufacturing technology were often held as closely guarded secrets in order to maintain competitive advantages. Thus the benefits of this new technology were available to the Army only when dealing with the contractor who developed it.

The AVSCOM MM&T Program exists in order to overcome these shortcomings by sponsoring the timely development of improved manufacturing methods, processes, and equipment which can be applied to the production of Army aircraft. One of the most important aspects of this program is the transfer of technology from the contractor who develops it under AVSCOM sponsorship to industry as a whole. Thus the new developments undergo even further refinement and development and, what is most important, wider application.

Project to Save $7000 per Engine

This section contains a brief description of a few current AVSCOM MM&T efforts being pursued.

The GE T700 turboshaft engine has been chosen by the Army to power the two new helicopter systems to enter the Army inventory, the UTTAS and AAH. AVSCOM's MM&T Program has played an important role in reducing the cost of this engine while maintaining required performance objectives.

One of the major AVSCOM MM&T efforts associated with the T700 engine is the development of fabrication methods for producing the one-piece compressor stages called "blisks". The term "blisk" refers to the design approach of combining the compressor blades and disks as single units rather than the more conventional design of separate disk with individual blades attached. The T700 compressor rotor assembly is composed of five forged blisks and a centrifugal impeller.

Milling, Casting Automated

The conventional manufacturing process for transforming the forgings into finished blisks involves rough cutting on a pantograph mill followed by hand finishing operations. Under an AVSCOM sponsored MM&T project, an automated fabrication process is being developed which involves rough cutting on four-spindle, numerically controlled, multiaxis mills, followed by abrasive-flow finishing. The production method developed by the MM&T effort is expected to save approximately $7000 per engine over the conventional fabrication technique.

In addition to this project, other AVSCOM sponsored MM&T work on the T700 engine includes development of a hot isostatic processing (HIP) method for fabrication of turbine disks and cooling plates to near net (final) shape, improved casting techniques for turbine blades with internal cooling passages, and development of a casting process for casting the titanium compressor casing. All of these projects will contribute significantly towards reducing the costs of buying and maintaining the T700 engine.

While the projects described above are only a portion of the total AVSCOM MM&T Program, they are excellent examples of the types of projects currently being sponsored by AVSCOM.

Objective Study Finds Thrust Areas

Some of the areas for future application of advanced manufacturing technology in production of Army aircraft are discussed in this section.

Battelle's Columbus Laboratories of Columbus, Ohio, recently completed a study under contract to AVSCOM which will assist the command in formulating a realistic five-year plan for developing and implementing advanced manufacturing technologies for the production of Army helicopters.

As part of their effort, they examined the major cost drivers which affect helicopter manufacture, with particular emphasis on identifying those areas capable of being affected by application of new manufacturing technologies. This information was gathered through extensive interviews with representatives of the major airframe and engine contractors as well as personnel from some of the major forging and casting companies and, also, companies involved in the fabrication of composite structures.

Based on the information gathered from these surveys, a group of major cost drivers which affect helicopter acquisition and operating costs were identified. These cost drivers are listed here:

- High part count
- High labor in assembly (nonautomation)
- Tooling costs
- Repair and maintenance
- Specifications/inspection
- Chip removal
- Design costs
- Composites
- Low production quantities

Considering these cost drivers and a number of project suggestions received from industry, important "thrust" areas were identified where appropriate manufacturing technology projects could have an impact on acquisition and life-cycle costs. These major thrust areas are:

- Composites
- Joining
- Repairability and Maintainability (R and M)
- Computer Numerical-Controlled & Aided Manufacturing (NC/CAM)
- Quality Control (QC)
- Reduction of part count
- Net (final) shape processing
- Hot Isostatic Processing (HIP)
- Production ready tooling
- Materials related development
- Forging
- Casting

Both the importance of these thrust areas and their potential for cost reduction through development of advanced manufacturing technology are dependent upon the helicopter subsystem to which they are applied. Considering the four major subsystems of a helicopter, the important thrust areas for each subsystem, according to the research firm's study, are shown below in order of importance.

Airframe	Engine	Rotor	Drive
Composites	Materials related	Composites	Joining
Joining	Casting	Production tooling	Composites
Part count	Joining	Joining	QC/NDT
Production tooling	Net (final) shape processing	QC/NDT	Forging
R and M	R and M	CAM	CAM
QC/NDT			

The key "thrusts" shown indicate areas associated with each major subsystem of the helicopter which offer significant potential for cost reduction by development of advanced manufacturing technology associated with that thrust. The ranking of thrust areas under each subsystem gives an indication of the relative importance of each thrust within the particular subsystem group.

Based on the identified cost drivers and thrust areas and numerous project suggestions received from industry, a summary of areas of major emphasis for development of future manufacturing technology for Army aircraft was presented by the Battelle study. These goals, grouped according to helicopter subsystem, are as follows:

Airframe—Reduction of part count and labor costs through the development of advanced tooling for manufacture of composite structures including important attention to joining and repairability.

Engine—Improved performance of advanced materials, both cast and hot isostatic processed to near net (final) shapes to reduce costs of turbine components.

Rotor—Continuing improvements in manufacture of fiber reinforced and honeycomb composite structures, including important attention to quality control (production and in-service) and advanced tooling for manufacturing and joining as applied to main and tail rotor blades, thereby increasing reliability and reducing costs.

Drive—Development of methods for manufacturing improved low-cost drive components and composite housings, including important attention to precision forging, nondestructive testing, and CAD/CAM.

The Target—Production Items

The results obtained from the Battelle study will be used both as an aid in AVSCOM's continuing effort to improve the effectiveness of the Manufacturing Methods and Technology Program and as a guide for formulating future projects. Always, an essential requirement will be to orient MM&T projects towards specific items actually to be produced in order to reap the benefits of reduced costs.

AVSCOM will continue to emphasize expanded communication of the results of all these MM&T efforts. In this way, AVSCOM's Manufacturing Methods and Technology Program will benefit not only the Army but the aviation industry as a whole.

US Army

ManTech Journal

The Umbrella Approach At Work

Volume 2 / Number 1 / Winter 1977

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US Army
ManTech Journal

Contents

ABOUT THE COVER:

Wide Spectrum of technological capability utilized by the Missile Research and Development Command is portrayed by the montage on this issue's cover. The man portable Viper missile, multiple components of the Improved Hawk missile, launch of the surface to surface Lance missile, nondestructive testing methods using liquid crystal techniques, and hybrid microelectronic circuitry represent only some of many technologies regularly a part of the MIRADCOM manufacturing technology effort.

Comments by the Editor

The year 1977 appears to be a critical one for us as a nation and a people. Industry is faced with only a few months of respite from our critical energy shortage; then it will have to operate until the cold months of early 1978 with the spectre ever in mind that those coming months may again cause major shutdowns of our production. And our economy will suffer damage as in 1977. The issue of energy conservation may very well make the continued survival of any industry that is a heavy fuel user directly dependent upon that industry's ability to reduce its energy needs.


DR. JOHN J. BURKE

So it is most timely that the Army ManTech Journal illustrate to industry how the military is taking the initiative toward conservation of fuel in several of its heavy energy user production facilities. The article in this issue on application of energy technology to Army munitions production processes points up methods that will reduce fuel consumption. In fact, almost every one of the articles describing new manufacturing techniques in this issue will ultimately effect savings not only in time, labor, and money, but energy, too. The purpose to which this publication is dedicated couldn't be more perfectly fulfilled than to bring information on operational energy conservation procedures to the industrial and military manufacturing complex. Much of this information may be translatable to the challenges faced by our readers.

It is interesting to note, too, the parallelism of the results of these new technologies with the objectives outlined by the Office of Technology Assessment in its December report to the Congressional Committee on Science and Technology. The long established (and in many cases, already implemented) MM&T goals of the Army dovetail neatly with the OTA report's guidelines for the manufacturing industry. These guidelines clarify industry's role in the nation's materials cycle.

One of the most critical problems manufacturers will have to face from now to eternity (not just for the next year) will be management of their energy allotments—management of the very highest level and most sophisticated nature. Articles scheduled for forthcoming issues of the Journal will offer some of these sophisticated techniques—techniques which the Army is heavily engaged in developing. Future issues also will include articles from industry, which will describe some new and unique techniques that will have application in both the commercial and military sectors.

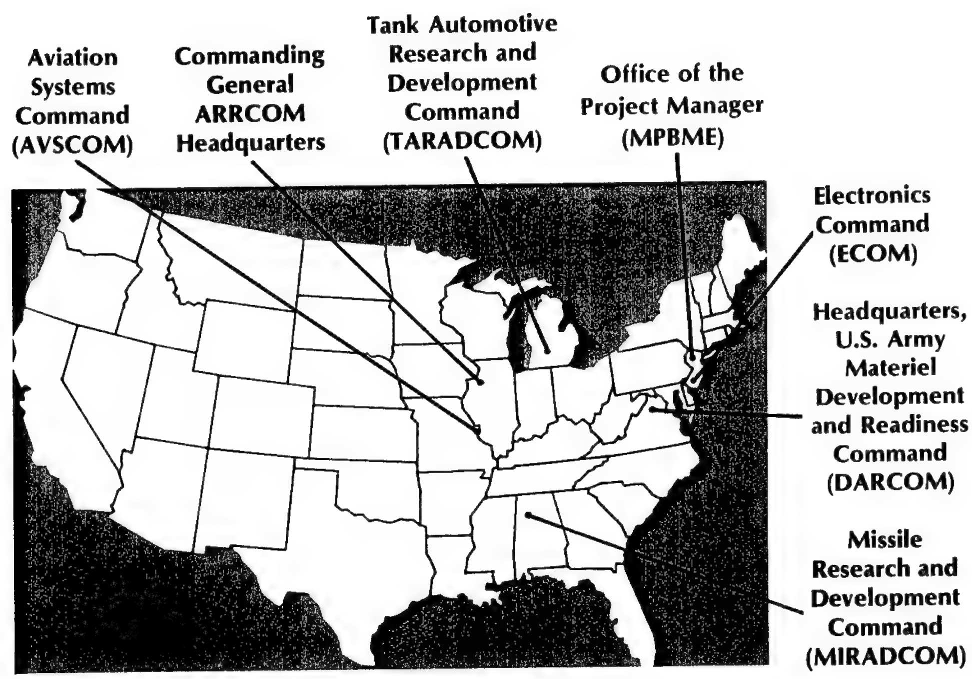
Response to the Army ManTech Journal has been startling, and a thoughtful review of the subscribers' profile has been most revealing. The subscribers include a mix of research scientists, production engineers, and marketing and management personnel, plus a large number of high officials of corporations; we believe these officials represent the attitudes of healthy, progressive firms. We further interpret this to be a reflection of the importance which top management in the United States places upon the improvement of our national manufacturing technology posture. As more line executives and production supervisors appear on our subscription list, we will know that the information being transferred to industry by the ManTech Journal will be at the implementation stage in industry.

There also is a gratifying number of subscribers who fall in the academic category, including many technical libraries and university libraries. This is important to our future manufacturing technology, as the engineering and management students who read these articles will be preparing for a dynamic rather than a static career in their chosen fields.

Former Assistant Secretary of the Army Harold L. Brownman offers some thought provoking commentary in his introductory article to this issue of the ManTech Journal. Mr. Brownman's first recommendation—regarding the related activities such as Value Engineering, Design to Unit Cost, etc.—has been fully adhered to by the umbrella approach of the Missile Research and Development Command. In its featured articles of this issue, the Command heavily emphasizes these functional areas of manufacturing technology as an integral part of its technological support capability.

This integrated effort is a further example of how Army commands are implementing their programs to meet the challenges outlined by the General Accounting Office report of last summer to the Congress. This report pointed out shortcomings of manufacturing technology in the United States. We feel that the challenges not only will be met but will be met in time to save our economy and production base from obsolescence. We expect the Army ManTech Journal to play a key role in meeting these challenges.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



An Army Initiative, A National Priority

U.S. Manufacturing Technology

The HONORABLE HAROLD L. BROWNMAN became Assistant Secretary of the Army (Installations and Logistics) on 9 October 1974. As Assistant Secretary he is responsible for materiel requirements, procurement and production, materiel management, logistics service, the military assistance program (less financial management), industrial mobilization, installations planning and programming, facilities and real property management, construction, family housing, and small business. Mr. Brownman was born in New York City on May 21, 1923. He attended the Polytechnic Institute of Brooklyn and received his B.E.E. in 1944. In 1949, he received his M.E.E. from the Polytechnic Institute. Mr. Brownman served in the Army Air Force from 1944 to 1946, after which he joined the teaching staff of the Polytechnic Institute. In 1948, he became an engineer with the Fairchild Engine and Airplane Company, and from 1950 to 1952 was an engineer with SERVO Mechanisms before joining TELE Register Corporation as an engineer. In 1954, he became Senior Engineer of the American Bosch Arma Corporation. From 1957 to 1958, Mr. Brownman was Laboratory Manager of the Fairchild Controls Corporation after serving as Research Engineer of the Fairchild Camera and Instrument Corporation. In 1958, he served as Program Director of the Fairchild Camera and Instrument Corporation. He was assistant to the Division Director of Airborne Instruments Laboratory, which is a Division of Cutler Hammer, from 1958 to 1967. In 1967, he became Vice President of Systems for LTV Electrosystems, Inc. Mr. Brownman joined the Central Intelligence Agency in 1970, where he held the position of Director of Special Projects until March 1973, when he became Deputy Director for Management and Services.

Editor's Note: Mr. Brownman submitted his resignation as the Assistant Secretary of the Army (Installations and Logistics) effective 31 December 1976. His new position is Vice President for Operations, Lockheed Missile and Space Company, Inc., Sunnyvale, California.

In these days of limited financial resources combined with continually increasing costs of ever more sophisticated weapons systems, it is impossible to overemphasize the importance of Manufacturing Technology as one aspect of an overall effort required to do more with less in the defense area. Of at least equal significance is the potential to be found in further exploitation of Manufacturing Technology as a means for regaining momentum toward increasing the productivity of our country's manufacturing capabilities—a national priority whose progress has been sharply arrested in recent years. This has occurred to the point where our lead in technology and the directly related area of productivity is being overtaken by foreign competition in a number of key industries.

What was just stated is certainly not news, at least to the readers of this magazine. These points do bear repeating, however, in that they establish the framework within which I view the success and the importance of the Army's Manufacturing Technology effort. In this connection, I want to state clearly and unequivocably that I am proud of the Army's progress and the results achieved, particularly over the last two years of my direct involvement.

Technology Transfer Critical

To tick off a few of the more significant achievements during this period, the Army's $40 million per year program in the key area of munitions technology is achieving major

benefits, as described in detail in the initial issue of this important new publication. This magazine—in conjunction with other related efforts to more widely publicize Army accomplishments—promises dividends in apprising the private sector of the nature of the Government effort, while at the same time stimulating their own imaginations in the direction of new or reemphasized technological endeavors.

The Missile Manufacturing Technology conference of September 1975 provided a promising start to the technique of utilizing a "top-down" approach in identifying cost drivers in the production of our major systems and focusing the minds of top Industry-Government talent on specific projects designed to reduce high cost areas involved in the manufacturing process. The Tank-Automotive conference held in October 1976, the Electronics conference of March 1977, and an Army Aircraft session scheduled within the next year also show great promise through utilization of similar techniques in these areas. Last, but far from least, is the reorganization of the Manufacturing Technology Office within DARCOM, which provides for direct access by its Director to LTG Sammet, DARCOM's Deputy for Materiel Development. This ensures the proper degree of emphasis and high level attention for this program.

Need High Level Support

By citing the above record of achievements, as impressive as they are, I do not mean to suggest that all of the problems have been solved and that we are now on an uncluttered path leading to early achievement of all of our Manufacturing Technology and Increased Productivity objectives. Unfortunately, this is not quite the case. Additional work and continued high level emphasis is required in the immediate future before we will be able to state unequivocally that ultimate Army goals have been reached or are in sight. To mention a few of the additional thrusts and areas of emphasis that will be required, and I cite these not as criticisms of what has transpired in the past but in the spirit of challenges for the future, I commend the following to your collective attention.

- First, we must consider the entire question of increasing productivity by reducing costs through improved Manufacturing Technology as an entity, without regard to artificial funding and organizational constraints. By this I mean that the Manufacturing Technology Program is generally considered by the Army as being within the narrow confines of Manufacturing Methods and Technology type projects financed under the five Army Procurement appropriations within the Production Base Support line item or activity within each account. This effort does not include such related activities as Value Engineering, Product Improvements, Production Engineering, and Design to Cost, which involve financing under the Operating and RDT&E appropriations and, at least in part, require different operating elements and diverse

channels for proceeding through review and approval. Somehow we need to come up with a better system of correlating, if not completely integrating, these directly related programs into a more efficiently managed entity.

- Second, additional emphasis is required within the R&D community on those research and development, testing, and evaluation financed activities which impact on production costs. Although current RDT&E programs make provision for cost cutting endeavors, such as Production Engineering and Design to Cost, such efforts generally have low visibility within the total community. It is here, particularly in the design effort with respect to new systems, that particularly high payoffs can be made possible in the production phase of the Weapons Acquisition cycle. I would strongly urge that the leadership within the Army RDT&E community devote an increasing proportion of their attention to this vital area. By taking actions necessary at this point, the overall task of keeping costs down and increasing manufacturing productivity is made relatively easier.
- Third, much additional work remains to be done in the area of documenting and maintaining an audit trail on cost savings resulting from Manufacturing Technology activities. By providing appropriate and valid documentation in this area, the task of competing for necessary resources to adequately fund the manufacturing programs involved is simplified.
- Fourth, as part of a concentrated and, in my opinion, mandatory effort to involve industry as a full partner in furthering the Army's Manufacturing Technology initiatives, detailed procedures and interfaces must be established to provide the appropriate parameters. Such procedures and interfaces, while fostering an atmosphere of mutual cooperation and trust, must at the same time ensure the protection of proprietary interests on the part of both Government and Industry and be consistent with the letter and intent of current procurement regulations.
- Last (and perhaps most important of all), high level emphasis on this program must continue if adequate funding is to be provided. Moreover, if objectives and benefits to be derived from Manufacturing Technology are to be realized, this emphasis must be at the forefront of top level Defense Management, a place which this program currently enjoys.

In conclusion, I want to commend the collective efforts of everyone involved in the Army Manufacturing Technology Program for a job well done. At the same time, if this effort is to continue to enjoy the level of success so far achieved, there is neither time nor cause for anyone to stand still and bask in the limelight of these recent activities. We must continue to move forward and to build from the plateau on which we currently stand. The defense effort as well as our national priorities dictate that this is our only viable course of action.

New Name! New Emphasis!

Overview of MIRADCOM ManTech Goals

Along with a new name—the U.S. Army Missile Research and Development Command (MIRADCOM)—a new emphasis is being placed on the role of manufacturing technology as an integral part of a missile system's development cycle. Our continuing quest to provide high quality, effective, and reasonably priced missile hardware to our combat forces is the driving motivation for pursuing and implementing manufacturing methods and technology programs which will provide the Army with the most hardware within available resources.

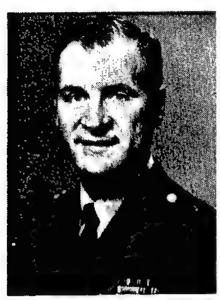
The combined workings of an effective ManTech organization, a sound technology base, and industry participation will insure that the problem identification, project execution, and implementation processes are meaningful and yield the desired results.

The MIRADCOM ManTech efforts are aligned under an umbrella approach similar to that initiated by the U.S. Army Materiel Development and Readiness Command (DARCOM), which combines Manufacturing Methods and Technology, Materials Testing Technology, Military Adaptation of Commercial Items, Producibility Engineering and Planning, Value Engineering, and Design to Unit Production Cost under a single organization that provides the necessary interaction for successful initiation and implementation of ManTech projects.

The full utilization of our basic technology resources as partners in the ManTech process will enhance the research/production interface necessary for providing our forces with affordable missile systems.

It is evident that without the cooperation and participation of industry, the goals of the ManTech program will not be met. By providing data regarding production costs, production bottlenecks, processing problems, and technical approaches to these problems, industry plays an important role in the execution and implementation of our manufacturing technology efforts.

Within our new ManTech structure, recent efforts in the fields of manufacturing simulation, cost driver analysis

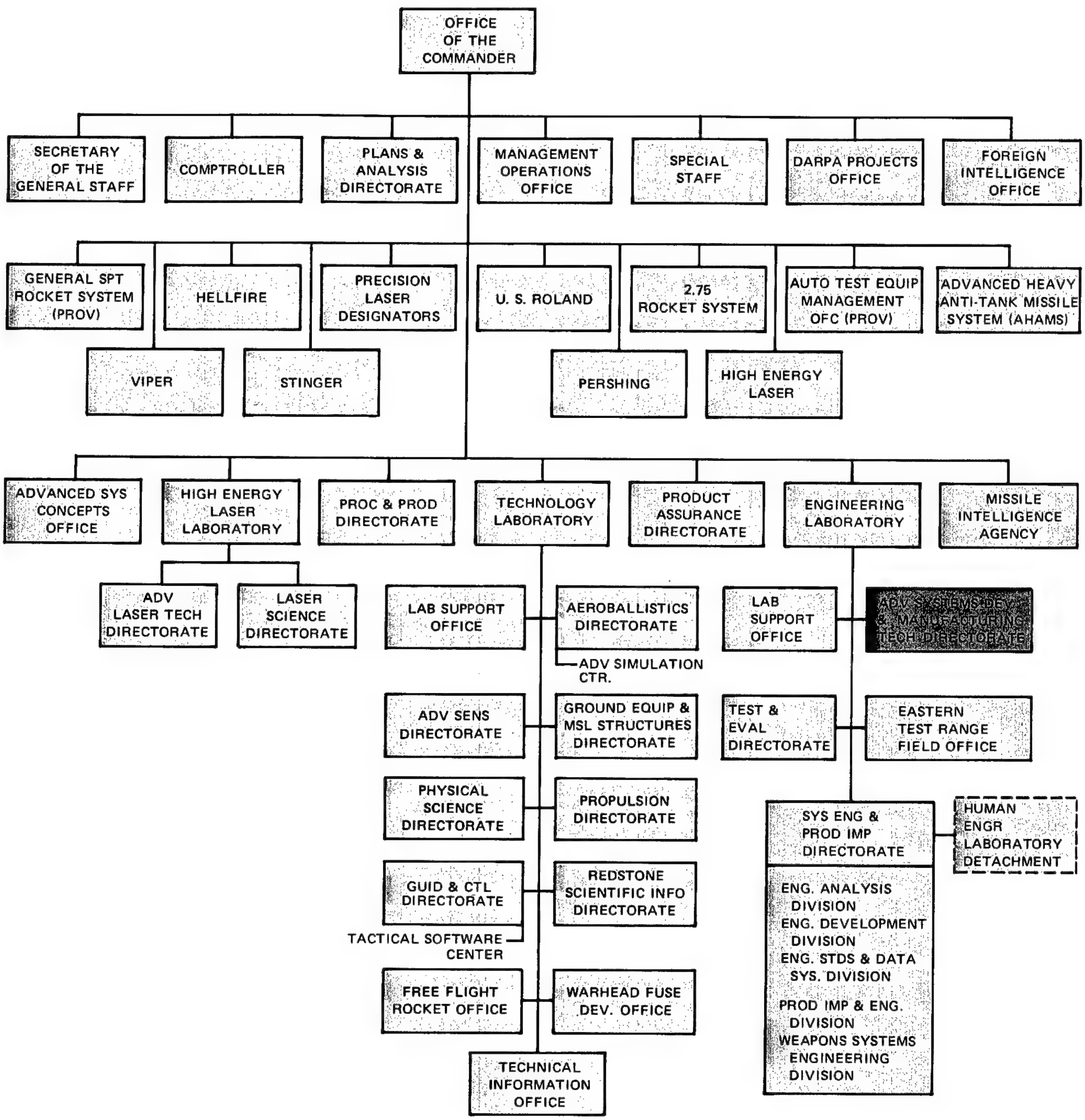


BRIGADIER GENERAL GRAYSON D. TATE, JR., is Commander of the U.S. Army Missile Research and Development Command (USAMIRADCOM) at Redstone Arsenal, Alabama. He assumed those duties on January 31, 1977. The general has been serving at Redstone Arsenal since April, 1974, when he took over direction of the Lance missile project. On October 1, 1975, he became Deputy Commander of the former U.S. Army Missile Command (USAMICOM). A 1950 graduate of the U.S. Military Academy, General Tate has had several assignments with missile units and in research and development of missiles and rockets. He has a Master's Degree in Aeronautical Engineering from the Georgia Institute of Technology and also is a graduate of the Command and General Staff College, the Armed Forces Staff College, and the Industrial College of the Armed Forces. He was born in 1929 in Mickey, Texas. Before being assigned to Redstone, the general was Director of the Gunnery Department, Field Artillery School, at Ft. Sill, Oklahoma. His first missile assignment came in 1954 as a battery commander in a Corporal missile battalion, the Army's first field artillery missile unit. Subsequently he commanded a Sergeant missile battalion in 1965; the 4th U.S. Army Missile Command in Korea in 1971; and also had Pentagon assignments on missile projects in the Office of the Army's Chief of Research and Development and the Office, Assistant Secretary of the Army (Research and Development). In a prior tour at Redstone Arsenal (1958 through 1961) he served as Chief, Research Plans Division, and Chief, Technical Intelligence Division, in the Army Ordnance Missile Command, which latter became the Army Missile Command.

and computer aided technical assessment will enable this command to more easily identify areas needing ManTech investigation, to determine risk, and to establish priorities. This new structure will also insure that all the relevant elements are included in the planning and execution process. These elements, whether they are project management offices or technology laboratories, are continuously involved from the initial phases of project formulation through completion and project implementation. We recognize that active participation of these elements is essential if maximum benefits are to be derived.

The challenges which confront our technology base and the opportunities they afford us are not taken lightly. We at MIRADCOM will continue to meet each challenge and vigorously pursue every opportunity to accomplish meaningful projects which will have significant economic benefit to the production of our missile systems.

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND (MIRADCOM)



New Technology Exploited to Maximum

Capabilities Geared

DARCOM'S Missile Manufacturing Technology Conference of 1975 clearly demonstrated that the Missile Research and Development Command (MIRADCOM) presently faces a challenge—a challenge to match an ever expanding technology to the need for improved and more efficient manufacturing processes. And like any challenge, it must be regarded as an opportunity to be taken advantage of, not a circumstance to be feared—in this case, an opportunity with a potentially high return in both labor and material costs, from the conceptual phase through prototype and production.

Recognizing the challenge (and the opportunities), MIRADCOM has developed a strong technology base to meet it, utilizing programs and facilities that best exploit technology advances so that these new techniques can be incorporated into missile systems production lines. This procedure ensures continued success in the production of new missile systems.

DR. JOHN L. McDANIEL was named Deputy and Technical Director, U.S. Army Missile Research and Development Command, Redstone Arsenal, Alabama in January 1977. Prior to that time he served as Director, U.S. Army Missile Research, Development, and Engineering Laboratory, U.S. Army Missile Command. His Federal employment began in 1942 with the Chemical Corps at the Huntsville Arsenal, where hs remained until accepting a position with the newly organized Ordnance Rocket Center at Redstone Arsenal. In 1960 he accepted the position of Technical Director, Research and Development Operations, Army Ballistic Missile Agency, where he remained until he became Technical Director, Research and Engineering Directorate, U.S. Army Missile Command. Dr. McDaniel was born in Guin, Alabama. He graduated *Summa Cum Laude* from Berry College, Mount Berry, Georgia, receiving a B.S. Degree in Chemistry in 1939. He received an M.S. Degree in Public Administration from the University of Alabama, a Doctor of Science Degree from Auburn University, and a Doctor of Laws Degree from Athens State College. He is an Adjunct Professor at the University of Alabama in Huntsville and a part-time professor at the Florida Institute of Technology in Huntsville. He serves on the University of Tennessee Space Institute Advisory Group, the Athens State College Board of Advisors, and the Visiting Advisory Committee, Mechanical Engineering Department, Auburn University. He has received the *Army Research and Development Achievement Award*, the *Meritorious Civilian Service Award*, and the *Decoration for Exceptional Civilian Service*, all of which are awarded at the Department of the Army level. His most recent award was the *Department of Defense Distinguished Civilian Service Award*, the highest that can be awarded by the Secretary of Defense. Dr. McDaniel has authored a number of technical publications and has patents in the field of guidance and control. He is listed in *Who's Who in America, Who's Who in the South and Southwest, the National Register of Scientific and Technical Personnel*, and in *American Men of Science*.

Missile manufacturing methods and technology programs at MIRADCOM have applied this technology in the past and will continue to do so in the following areas of basic manufacturing technology that are required for missile systems development:

Guidance and Control Systems
- Advanced Simulation
- Microelectronics
- Software/Hardware
- Ground Laser Designators

- Lasers/Optics
- Seekers/Sensors
- Propulsion
- Materials Engineering
- Metrology and Calibration
- Product Assurance.

This article provides an overview of MIRADCOM'S basic technology capabilities in these areas in support of its MM&T programs.

Guidance/Control System Design Among Top Priorities

A primary mission at MIRADCOM is the research, design, and development of guidance and control systems for missiles and rockets. This mission includes technical support to all elements of parent organizations and other government agencies engaged in missile development.

The overall capability is better defined by considering some specific programs either completed or in progress at MIRADCOM.

- Design of a Ring Laser Gyro, a strapdown, digital inertial guidance system designed for ballistic surface-to-surface missile systems
- Design and fabrication of a multipurpose digital processor using advanced bipolar microprocessor technology
- Design of two autopilot algorithms for the T6 missile simulator
- Development of a helicopter mounted target acquisition designation system that will be used against tactical targets under day or night conditions

for Full Support

- Development of improved methods for generating and testing microprocessor tactical software
- Design, development, and demonstration of an optimized, compliant surface, air bearing gyro stabilizing system with pneumatic torques and a unitized detector preamplifier package for high acceleration semiactive seeker applications
- Exploration of the feasibility of solid propellant nitrogen generators as an energy source to control actuator flow and other gas driven guidance and control components
- Feasibility demonstration of a target location system similar to that proposed for the Advanced Attack Helicopter (AAH)
- Study of a control concept in which a sensor controller is mechanized to guide a missile with no requirement for inflight power, preflight power electronics, or preconditioning
- Feasibility investigation of a low-cost laser beamrider guidance concept for improving the boost phase trajectory accuracy of free flight rockets
- Provision of technical support for an MM&T program to develop a laser seeker head with performance equal to or better than that of the Army Laser Seeker (ALS).

The guidance and control facilities at MIRADCOM include an advanced simulation center, a microelectronics facility, software and hardware capabilities, and a ground laser designator development capability.

SIMULATION FACILITY EVALUATES ADVANCED SYSTEMS. As part of their guidance and control support, MIRADCOM operates a center for computer simulation of advanced guidance systems which contains a hybrid computer complex and three environmental physical effects simulators—infrared, electrooptical, and radio frequency. These allow simulation from concept formulation to production and deployment. Program costs are reduced through optimization of time, minimization of flight testing, and early identification of potential false starts.

MICROELECTRONICS PLAYS KEY ROLE. About 5 years ago, recognizing that advanced missile development relies heavily on microelectronics for continuing growth, MIRADCOM established a facility that now has the capability of designing and producing single sided, double sided, or multilayered printed circuit boards and also flexible wiring boards or circuits. Another capability is the design and production of hybrid microelectronic circuitry utilizing thick film technology; equipment for the use of thin film technology is currently being installed. MIRADCOM also designs mechanical assemblies and produces them by chemical milling.

SOFTWARE/HARDWARE CONTROL CENTRALIZED. The DoD now requires all weapon systems programs to emphasize both development and maintenance of computer software programs. To meet this requirement, MIRADCOM developed a tactical software facility which supports program offices during weapon system development with complete verification and validation of tactical software. It also provides post-deployment maintenance of AN/TSQ-7s, Patriot, Hawk, and Pershing software.

With this capability, MIRADCOM has brought all software programs under one organization, insuring consistency in coordination, configuration control, design, and test methodology. The center reduces both development and maintenance costs. Although this particular facility is new, the Command has 15 years' experience in software development.

GROUND LASER DESIGNATORS OFFICE SET UP. The recently established Ground Laser Designators Project Office is responsible for development, procurement, fielding, and logistic management of three systems—The Ground Laser Locator Designator (GLLD), the Laser Target Designator (LTD), and the Modular Universal Laser Equipment (MULE). The GLLD is a man portable system consisting of three modules—a laser designator/rangefinder (LDR), a tracking aid with target bearing resolves, and a lightweight tripod. The LTD is a hand held target marking device for equipment that includes laser acquisition/tracking features. The MULE is a man packed functionally modular system for determining relative target location and for designating targets.

High Energy Laser Laboratory A Total Facility

The Army High Energy Laser Laboratory at MIRADCOM provides a research and development capability in high power, high energy laser science and technology. This laboratory monitors and reviews research and development; coordinates planning and development of

technology in basic and applied research required for future high energy laser devices and applications; and provides technical control, support, and scientific advice on advanced development efforts.

With the facilities and expertise available at this Laboratory and its supporting contractors, complete laser systems can be built and tested, new concepts can be developed, and a wide range of laser applications can be demonstrated and proof tested.

The Laboratory is supported by the Advanced Laser Technology Directorate (ALTD) and the Laser Science Directorate (LSD). The ALTD develops and maintains the technology to provide fundamental information supporting high energy laser component and system development. It also performs and directs related advanced development and monitors military and civilian research and development efforts.

The LSD plans, conducts, manages, and reviews research and development in all technical areas associated with high power, high energy laser science and technology.

Seeker Technology Broadly Applied

Through its Advanced Sensors Laboratory MIRADCOM is responsible for the development and improvement of sensors and sensor systems for the Army's missile and projectile systems. This Laboratory is also the principal agent for the Development and Readiness Command's terminal homing programs and provides engineering and technical support to project managers throughout MIRADCOM. Within these functional areas, the Laboratory plans and executes a broad based program of research and exploratory development in sensor technology and terminal homing.

In addition, the Laboratory is involved in a wide variety of MM&T programs. In one of these, nonmetallic materials were investigated as the primary structural material for laser seekers. An electronics shroud was designed, tested, and evaluated and a manufacturing plan developed. It was found that an all plastic shroud could be produced at only one fourth the cost of an aluminum shroud.

Another MM&T program was directed toward production of spinning mass implemented laser terminal homing seekers. The program was designed to reduce procurement time and costs and to provide state of the art production processes and techniques. The technology developed in this program has been specifically applied to the Tri Service Laser Seeker, the Copperhead (CLGP) Seeker, and the Active Laser Seeker.

Propulsion Research Sophisticated

The Propulsion Laboratory at MIRADCOM functions as control monitor for all Army rocket-propulsion R&D activity. It engages in research in solid, liquid, and advanced propulsion technology, and also investigates propellants, ignition systems, interior ballistics, gas operated power systems, and propulsion mechanics. In addition, it provides technical support during engineering development and fielding of missile systems.

The Laboratory's efforts are designed to meet such specific propellant requirements as:

- Wide range of burning rates—from less than 0.1 in./sec to 15-20 in./sec
- Operational mechanical properties at a wide temperature range— -65 F to 160 F
- Long shelf life—propellant dependability after storage
- High performance—thrust per pound of propellant as great as possible
- Low signature—smoke and flash minimal relative to detection of the launch position and possible interference with the guidance system
- Low cost.

Several significant accomplishments reflect propulsion capabilities at MIRADCOM. Recently, carborane compounds were synthesized and characterized as ballistic modifiers. As detailed in another article in this issue, N-Hexylcarborane was prepared and, following development of a manufacturing process, scaled to a 20 gallon reactor. During an MM&T program, a safe, economic manufacturing process was developed.

A low cost, high burning rate propellant system for the VIPER missile was developed and optimized in another MIRADCOM program. Propellant manufacturing techniques were established along with methods to prepare ultrafine ammonium perchlorate. Ammonium perchlorate manufacture is presently under further study in an MM&T program. Other MM&T programs related to the VIPER missile involve a disposable mandrel and a rapid cure propellant. These programs are intended to reduce both manufacturing and facility costs.

To aid in the study of low-signature propellants, the Propulsion Laboratory now has a Signature Characterization Facility (SCF) in full operation. A theoretical model of the SCF and a smoke visibility model are now being developed which will allow correlation of chamber data with raw flight data.

Ignition systems are another speciality of the

Laboratory. Through the years, the Laboratory has developed igniters for various missile systems ranging from PERSHING to DRAGON.

Materials Engineering Key MM&T Element

MIRADCOM has developed technical expertise in metallic, chemical, and ceramic missile materials and materials processing. Metallurgical areas of interest include foreign materials exploitation, physical metallurgy, joining, corrosion, mechanical property determination, and metal matrix composites. Chemical areas of interest include analytical chemistry; plastics, adhesive, and elastomers; organic coatings and organic matrix composites; and degradation mechanisms. Ceramics research involves ceramic and carbon-graphite composites, radomes, heat resistant coatings, and elastic components.

In addition, all Army missile systems are supported on a continuing basis. These support functions include:

- Detailed identification and analysis of unknown materials by both wet chemical and instrumental methods
- Evaluation of new materials that have potential uses in missile hardware applications
- Compounding or modifying materials or processes for new applications
- Prototype fabrication of missile and support hardware.

Programs using these capabilities include developmental efforts for radome materials and ferroelectric and dielectric materials evaluation for high temperature applications.

The materials engineering laboratory is currently supporting manufacturing technology programs to develop an economical manufacturing process for the production of lithium ferrites and glass fibers.

Army Standards, Calibration Provided

Colocated at Redstone Arsenal with the MIRADCOM laboratories is the U.S. Army Metrology and Calibration Center (USMAC). Part of MIRADCOM's sister command—the U.S. Army Missile Materiel Readiness Command—the Center provides the Army with a means for establishing traceability between test equipment and national standards maintained by the National Bureau of Standards (NBS).

The Center manages a single program that is applicable to all Army units, organizations, installations, commands, and activities that establish calibration requirements or provide and/or receive calibration.

Two of several operational elements within USAMCC are of particular interest. One of these, the Army Standards Laboratory (ASL), is the Army's highest measurement authority. ASL provides calibration services for all Army area calibration labs and other calibration activities. ASL has a number of special projects under way to automate manual procedures, such as the automated standard cell calibration system. This system, capable of measurements with resolution on the order of 20 nanovolts, analyzes all Army Volt Program data. A second ASL special project is the automated micropotentiometer calibration system which has reduced time and uncertainty by nearly 50 percent. A third example of ASL special projects is the Deadweight Force Facility, applying forces up to 102,000 pounds with an accuracy of better than 0.01 percent.

The second USAMCC organizational element of particular interest is the Metrology, Development, and Engineering Division. Programs in progress there include work in lasers, electrooptics, and cryogenic electronics; development of a new RF measurement technique using six port networks; an investigation of solid state pressure transducers; and the development and application of automated calibration systems.

Product Assurance Capability Available to Industry

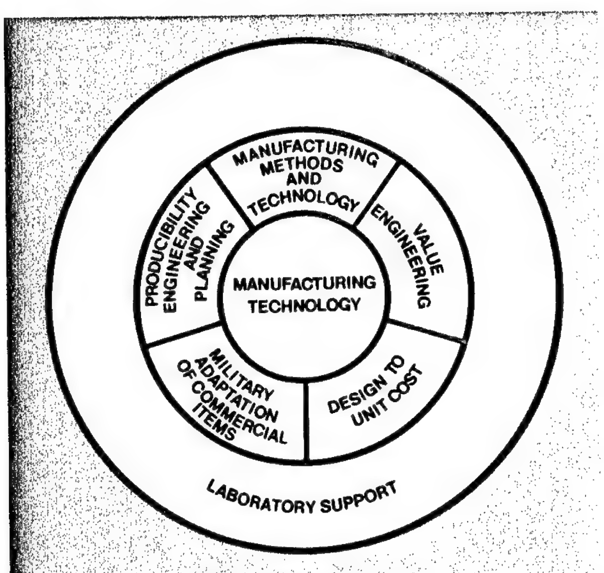
Product assurance and evaluation testing capability within MIRADCOM provides for complete flight, static, electrical-electronic, microwave, mechanical, and environmental testing for missile systems and components, both inert and explosive. Sophisticated facilities for all phases of missile and rocket testing and evaluation have been developed during the past twenty-five years. Activities include the conducting of research related to testing and calibration technology and methodology and, also, analysis of system effectiveness throughout the life cycle of the system. This extensive technology base is utilized to ensure product uniformity and quality from conceptual phase thru the system's life cycle.

Although the primary capability is in support of Army rocket and missile systems, the facilities and services are available to other government agencies as well as private industry.

W. K. PATTERSON is Chief, Manufacturing Technology and Materials Engineering and Development, Advanced Systems Development and Manufacturing Technology Directorate, MIRADCOM. He holds a Bachelor of Electrical Engineering Degree from Clemson University (1951). He began his career at the Charleston Naval Shipyard as a designer; after 3½ years there he joined the Army's Von Braun Missile Team at Redstone Arsenal, which designed and developed the Redstone and Jupiter Missile Systems. When Marshall Space Flight Center was formed in 1960, he chose to remain with the Army Missile Command in research and development. He has made numerous contributions to the successful design, development, and production of numerous Army Missile Systems during his more than 27 year career; some of these systems are Pershing, Lance, and Dragon.

Give Thrust to Sound Programs

Command Technologies Relate to ManTech



BASIC TECHNOLOGY AREAS

Success for any ManTech effort is dependent upon the expertise that surrounds it. An awareness of the available base and the ability to provide basic technological guidance are essential to the development and implementation of ManTech program objectives, and reliance on this sound foundation is a mandatory prerequisite for formulating ManTech goals and achieving cost reductions.

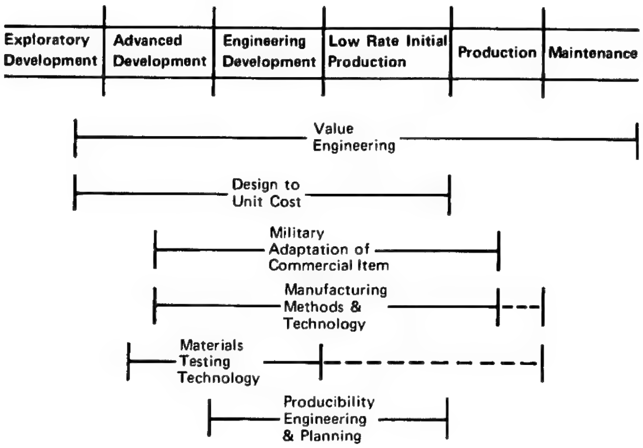
The ManTech program at the Missile Research and Development Command consists of five functional areas of technology:

- Manufacturing Methods and Technology
- Producibility Engineering and Planning
- Military Adaptation of Commercial Items
- Design to Unit Cost
- Value Engineering.

Their interrelationships within the ManTech program are as follows:

Manufacturing Methods and Technology spans the life cycle of a weapon system design concept from its advanced development thru its first production, and perhaps even beyond if production quantities support continued savings. The purpose of this technological area is to develop new

manufacturing methods or improve existing technology in order to reduce cost, increase reliability, prove prototype production equipment, and enhance antipollution or safety measures. A subfunction of MM&T is the **Materials Testing Technology** program, which provides for testing improved methods or procedures and the equipment used in the testing. Inputs to the MM&T program are derived from analysis of weapons cost data and briefings with both industry manufacturing representatives and other Government agencies. MM&T relates to the Design to Unit Cost and Producibility Engineering and Planning functions by



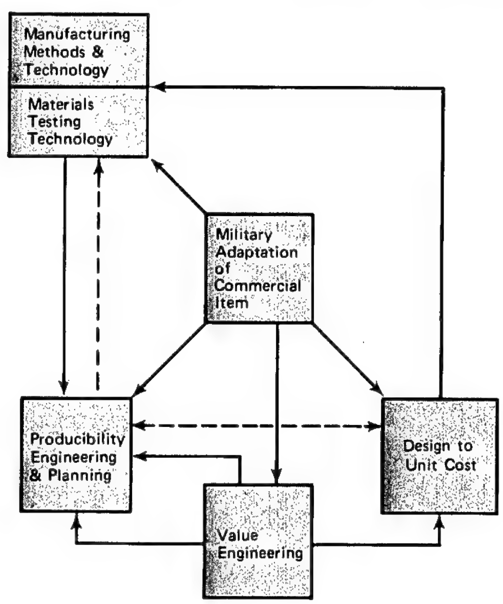
providing methods/techniques and equipment that will satisfy production goals.

Producibility Engineering and Planning spans the life cycle of the particular weapon system from its engineering development phase thru its low rate initial production. The purpose of this technological function is to ensure a smooth transition from development to production of a specific system. It establishes the production technical data package, production techniques, inspection techniques, production processes, equipment, and tools. The PEP function changes as the weapon systems development cycle evolves, with engineering and planning needs emerging as the program progresses. The function provides the avenue for implementation of successful MM&T projects and also identifies potential MM&T projects that could be accomplished to support future procurements.

Design to Unit Cost appears on the scene early in the life cycle of a weapons system, beginning to exert its influence during the exploratory development phase and continuing thru advanced development and completed engineering development. This function serves to establish life cycle cost goals that are not only achievable but that challenge designers, engineers, and program managers; cost is treated on an equal basis with technical requirements and performance objectives. The function is derived from the need to provide a final detailed estimate of the baseline cost for the proposed weapon system which addresses "Life Cycle Costs" and recommends an "Average Unit Flyaway Cost" threshold. After Defense Systems Acquisition Review Council I review and approval, the first official design to cost goals are included in the approved Development Concept Paper. After DSARC II review and approval, design to cost goals are used for full scale development. The function's effectiveness is reflected by the number of MM&T projects initiated to support the system and by the amount of investigation and tradeoff analysis done during the PEP phase.

Value Engineering constitutes the only all encompassing function of the five basic technological areas, spanning the entire life cycle of the weapon system from early exploratory development through final maintenance programs. Its purpose is to reduce total systems cost thru initiation of design, process, equipment, specification, and maintenance changes which allow achievement of mission objectives at reduced costs. Value engineering is derived from the needs of the program and project managers and chiefs who are responsible for R&D, production, and maintenance efforts, and receives its primary emphasis from their technical directions. A plan to conduct VE studies on a systematic basis is established for each major item or weapon system. Value engineering helps satisfy design to unit cost production goals and provides incentives toward implementation of completed MM&T projects.

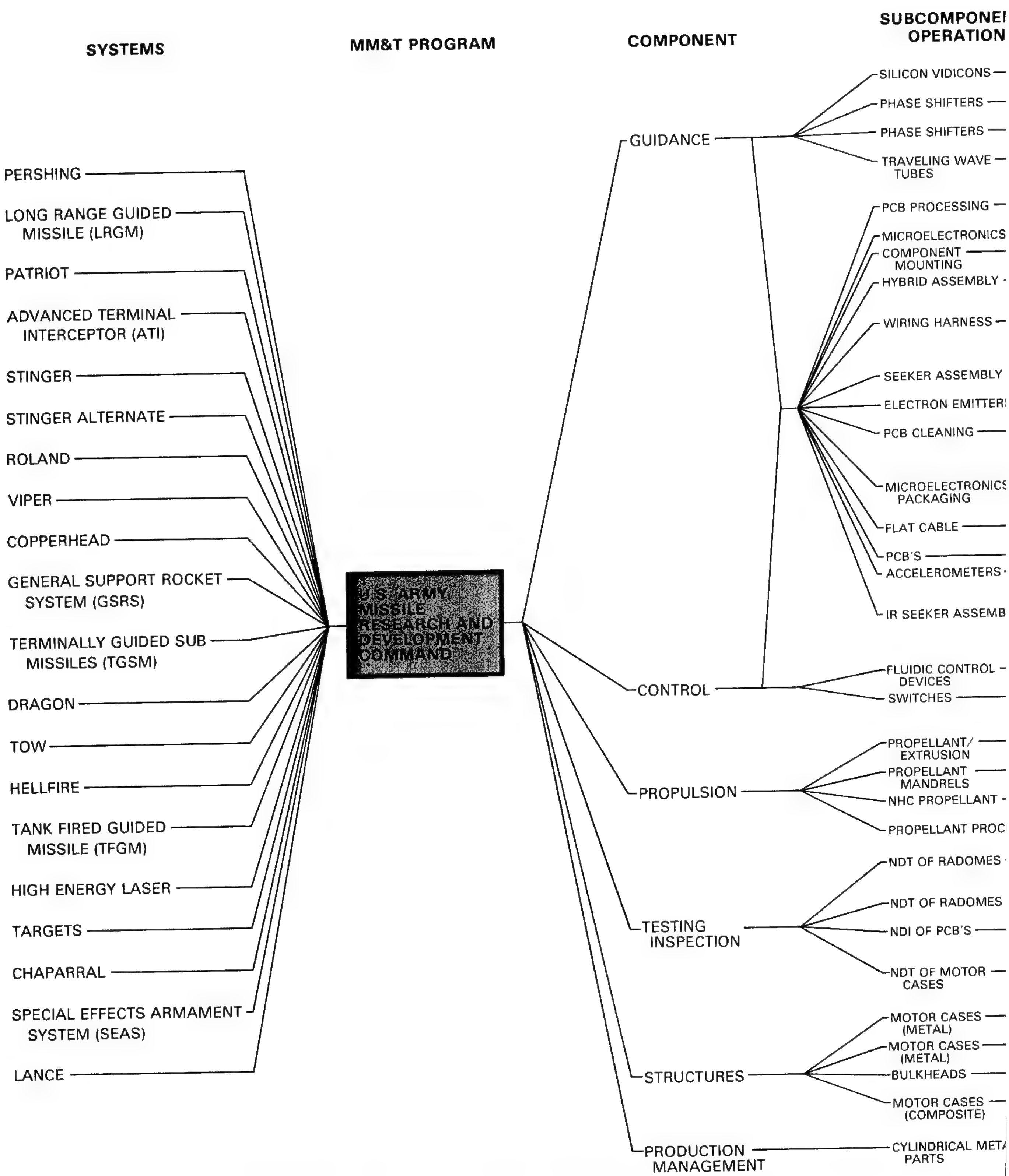
Military Adaption of Commercial Items can come into a weapon system program at any time during the system's life cycle, satisfying a particular military requirement in the shortest time and/or at the least cost by utilizing an item which is currently available thru a commercial source. It is derived from the review of major equipment requirements by the project managers and development organizations,



who establish potential candidates for the particular MACI program. This function is related closely to the experience of program managers in formulation of MM&T programs, those with extensive experience helping to establish MACI program requirements, costs, and return on investment ratios to adequately prepare program submissions.

MM&T PROGRAM: U.S. ARMY MISSILE RESEARCH AND DEVELOPME

SPIDERCHART



PROJECT	Reduce Manufacturing Costs	Required for Technical Data Package	Solve Production Obstacle	Facilitate Quantity Production	Validate Prototype Equipment	Prove Producibility	Improved Reliability	Energy Conservation	Electronics Fabrication	Automated Electronics Fabrication	Electronics Testing	Chemical Processing	Materials Processing	Electro-Optics	Materials Handling	Materials Testing	Metal Removal	Net Shape Processing	Computer-Aided Manufacture
MPROVED MANUFACTURING PROCESSES FOR SILICON VIDICONS	●			●		●				●									
IANUFACTURING TECHNIQUES FOR THE PRODUCTION OF DIODE PHASE SHIFTERS	●					●			●										
RODUCTION OF LITHIUM FERRITE PHASE SHIFTER FOR PHASED ARRAY RADARS	●								●										
UTOMATED PRODUCTION METHODS FOR TRAVELING WAVE TUBES	●			●						●									
DDITIVE PROCESSES FOR FABRICATION OF PRINTED WIRING BOARDS	●					●			●										
CREENING OF ELECTRONIC COMPONENTS	●						●				●								
RODUCTION METHODS FOR MOUNTING NONAXIAL LEAD COMPONENTS	●		●		●		●			●									
OW-COST PRODUCTION METHODS FOR HANDLING HYBRID CHIPS VIA A TAPE CARRIER LEAD FRAME	●					●	●			●									
PPLICATION OF COMPUTER-CONTROLLED MANUFACTURING PROCESS TO METHODS FOR AFFIXING ELECTRICAL CONNECTORS TO CABLES (CAM)	●			●	●					●									
ANUFACTURING PROCESSES FOR LASER TERMINAL HOMING SEEKERS	●	●		●		●			●										
ANUFACTURING METHODS FOR PRODUCTION OF FIELD EFFECT EMITTERS	●					●	●		●										
STABLISHMENT OF PRODUCTION CLEANLINESS CRITERIA AND PROCESSES FOR PRINTED WIRING BOARDS AND ASSEMBLIES	●						●					●							
RODUCTION PROCESSES AND TECHNIQUES FOR THE SEALING OF HYBRID MICROCIRCUIT PACKAGES	●						●		●										
ANUFACTURING MULTILAYER RIGID-FLEX ARNESSES	●								●										
RODUCTION OF CIRCUIT CARD HEAT PIPES	●					●			●										
IPROVED MANUFACTURING PROCESSES FOR INERTIAL GRADE QUARTZ FLEXURE ACCELEROMETER	●												●						
IPROVED MANUFACTURING PROCESSES FOR INFRARED IMAGING SEEKERS FOR TERMINAL HOMING MISSILES	●			●										●					
UIDICS MANUFACTURING AND ASSEMBLY PROCESSES	●											●							
ANUFACTURING TECHNIQUES FOR STATIC SWITCHES (CAM)	●	●				●			●										
RODUCTION METHODS FOR EXTRUDABLE HTBP PROPELLANTS	●												●						
ETHODOLOGY FOR PRODUCING LOW-COST DISPOSABLE MANDRELS	●														●				
ROCESS DEVELOPMENT FOR CARBORANE MANUFACTURE	●	●		●	●								●						
EPLACEMENT OF TPH-8156 AND TPH-8159		●	●			●							●						
N ACOUSTICAL HOLOGRAPHIC PASSIVE NONDESTRUCTIVE TESTING TECHNIQUE FOR CERAMIC RADOMES	●						●									●			
OMPUTER-AIDED SPECKLE HOLOGRAPHIC COMPOSITE VOID DETECTION SYSTEM (CAM)	●						●									●			
UTOMATIC OPTICAL INSPECTION OF PRINTED CIRCUIT BOARDS AND COMPONENTS (CAM)	●		●		●						●								
PPLICATION AND NDT OF LINE PIPE FOR MOTOR COMPONENTS	●					●										●			
RODUCTION METHODS FOR STRIP LAMINANT CASES	●			●		●	●											●	
ANUFACTURING METHOD FOR HIGH SPEED MACHINING OF ALUMINUM	●							●									●		
RODUCTION METHODS FOR PRODUCING SQUEEZE CASTINGS	●																	●	
UANTITY PRODUCTION TECHNIQUES FOR COMPOSITE ROCKET MOTOR COMPONENTS	●					●												●	
OMPUTERIZED PRODUCTION PROCESS PLANNING	●							●											●

Missiles Envelop Wide Scope

Highlights of Major Achievements

The following articles on Phased Arrays, Carborane Production, A New Electronic Material, Cable/Harness Fabrication, Laser Seekers, and Liquid Crystal Nondestructive Testing represent a potential savings of $78,000,000 over a time period of six years. These achievements are typical of the outstanding results of the MIRADCOM Manufacturing Methods and Technology Program. The highlight articles are followed by Brief Status Reports on MM&T projects currently under way.

Thick Film Technique Practical

Phased Arrays Mass Produced

Less costly antennas possessing higher reliability and better performance are now becoming available following a recently completed MIRADCOM manufacturing technology program. Automated mass production is now possible with the application of thick film screen printing, which has revolutionized fabrication of these complex components.

These advances in phased array antenna technology have brought about significant cost reductions in the fabrication of antenna components such as radiators, phase shifters, and RF power distribution networks.

The cost of a phased array antenna has been very high because of the large quantity of these components required for each antenna—typically, in the thousands. In order to minimize fabrication, assembly, and testing costs, a large number of these radiators, phase shifters, and power distribution networks may be combined to form an integrated subarray module. This subarray module then becomes the basic building block of the phased array antenna instead of the individual radiators and phase shifters. The new fabrication procedure will save $23,000,000 over the next six years, based upon cost differentials applied to anticipated future purchases of these components.

Modules Become Basis

Under a Manufacturing Methods and Technology Program, the feasibility of fabricating a 64 element integrated subarray module was demonstrated by Hughes Aircraft Company. A photograph of the module is shown in Figure 1. This module combines 64 radiators, 64 phase shifters, and 64 power distribution networks into a compact, lightweight integral package. The key manufacturing breakthrough in the construction of this module was the use of thick film painting technology to fabricate two microstrip diode phase shifters, two disc radiators, and a power divider on one common dielectric substrate.

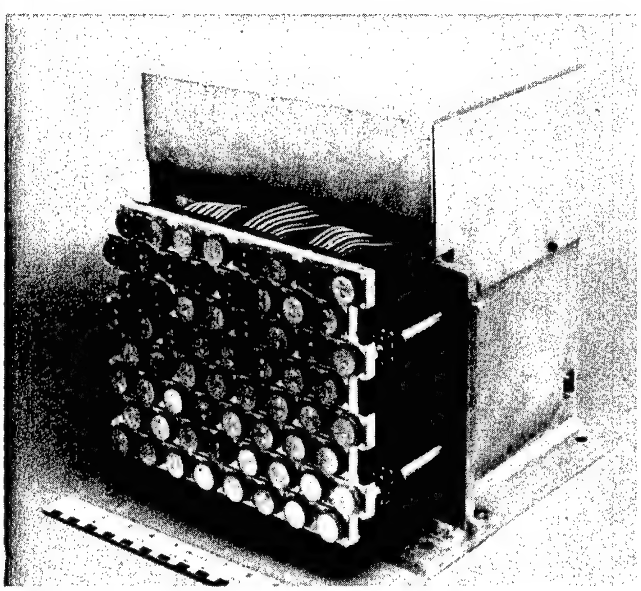


FIGURE 1

DOUGLAS SAUNDERS is Group Leader for Materials Testing Technology, Production Engineering, and Producibility Engineering and Planning. He has been involved in the Manufacturing Technology Program at MIRADCOM for the past six years. Mr. Saunders has been with the government 33 years and has held positions in the Army, Air Force, Navy, and NACA. Mr. Saunders received a B.S. Degree in Mechanical Engineering from Indiana Technical College prior to his employment with the Lewis Propulsion Laboratory (NACA) in Cleveland, Ohio. He was Chief of the Instrumentation Section of the Climate Laboratory, Eglin AFB, prior to his transfer to ABMT, Redstone Arsenal, Alabama, in 1957.

Microstrip phase shifters are commonly fabricated with alumina substrates which have been metal coated using thin film technology. For many microstrip applications, the cost of the substrate is not significant relative to the cost of the system. However, in the case of phased array antenna systems, where thousands of such phase shifters are required, the high cost of thin film technology becomes a distinct disadvantage. The use of less costly thick film technology for substrate fabrication presents an attractive alternative which not only offers savings but potential additional benefits in both reliability and performance.

Reliability Thru Better Fabrication

The high degree of reliability of thick film metallization is attributable to a number of factors, which include:

- Good adhesion of reactive bonded conductors to the alumina substrate
- Use of special solderable materials which are resistant to leaching

- Low loss, fritless gold transmission lines
- Use of thick film capacitors of higher voltage capability than their discrete thin film counterparts—they form a monolithic part of the substrate (requiring no interconnection leads that could become loose)
- Thick, trouble free metallization through holes in a screen.

The **low cost associated with thick film technology** is primarily the result of substrate fabrication by the method of screen printing. Each required material is added to the alumina substrate in the precise geometry and to a controlled thickness by deposition through a stainless steel screen on which a stencil has been photographically defined. This process is considerably simpler than that used for thin film metallization, which required deposition of blanket layers on the substrate and subsequent photoresist application, exposure, and chemical etching. The following chart contrasts the thin and thick film processes and includes an estimate of the labor required to produce an identical 2 x 3 inch substrate. Screen printing can be performed at high rates (in excess of 3000 prints per hour) using a production printer shown in Figure 2, along with a continuous belt firing furnace.

Comparative Steps in Thin and Thick Film Processes

Thin Film	Thick Film
Clean	Clean
Vacuum deposit front metallization	Print, dry and fire front metallization
Vacuum deposit back metallization	Print, dry and fire back metallization
Apply photoresist and bake	
Expose photoresist	
Develop photoresist	
Etch gold/nichrome	
Strip resist	
Apply photoresist and bake	
Expose photoresist	
Develop photoresist	
Selective plate	
Strip resist	
Labor required—1.5 hr	0.2 hr

FIGURE 2

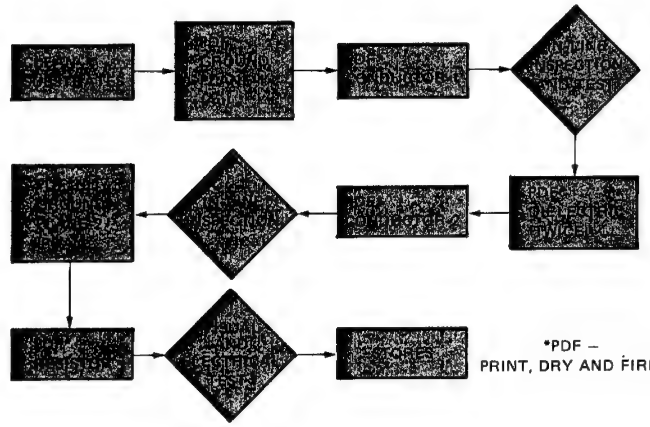


FIGURE 3

The thick film substrate fabrication process for a typical phased array application is shown in Figure 3. This substrate requires separate screen printing steps to deposit the gold ground plane, solderable ground plane area (PtAu), capacitor dielectric, capacitor counter electrode, and thick film resistor.

The assembly process of a typical phased array module is shown in Figure 4. This process involves attachment (by high temperature solders) of various discrete active devices and the mounting of hardware, connectors, and radiating elements.

Technique Easily Automated

Fabrication of phased array modules is a continuous in-line process which is easily automated for mass production. The thick film deposition method is inherently reproducible and offers a significant cost advantage over alternative methods.

The manufacturing methods established under this MM&T program have clearly demonstrated the feasibility of constructing low cost, lightweight phased arrays using the integrated subarray module as the standard building block for any phased array radar application.

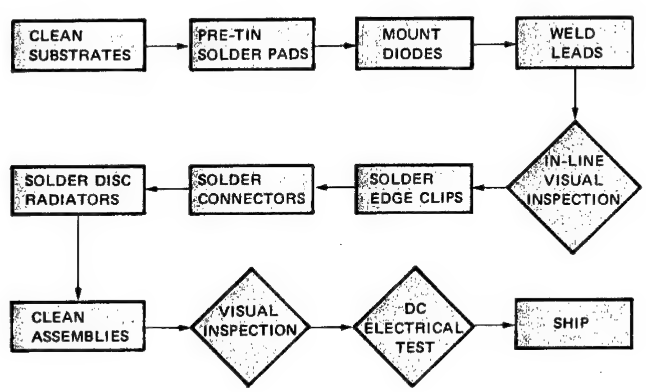


FIGURE 4

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Industry, Military Exchange Technology

Carborane Technique: Classic Example

A $5.3 million MIRADCOM investment in MM&T will be repaid within four to six months after a new carborane production facility becomes operational in 1979. Subsequent savings will amount to $15 million annually. This program, which began in 1970, is the result of a deliberate effort by MIRADCOM to effect government/industry technology transfer. As a result of this interface, pilot plant operations have demonstrated a 49 percent increase in product yield.

Boron hydride derivatives such as pentaborane, decaborane, etc., were initially considered prime candidates for rocket and guided missile fuels. Unfortunately, the undesirable chemical and physical properties of these compounds made them difficult to use in solid rocket propellants. In the mid 1960's the MIRADCOM initiated a synthesis program designed to prepare and evaluate boron derivatives that would circumvent the objections of the boron hydrides and be more compatible with conventional solid rocket propellants.

As a result of that work, a series of useful carborane compounds were prepared and a family of solid rocket propellants developed that exhibited improved ballistic and mechanical properties. New propellant compositions were established, optimized, and characterized. One of these compositions is currently being used as the propellant for the VIPER Missile System, and other compositions are being considered as prime candidates for future missile systems.

Two Processes Available

Carboranes that exhibit a wide range of chemical and physical properties can be prepared by reacting the appropriate hydrocarbon derivative with decaborane. Two basic processes for the preparation of the desired carboranes are available; one of the processes involves the **pyrolysis of diborane to decaborane:**

$$5B_2H_6 \xrightarrow{\text{heat}} B_{10}H_{14} + H_2$$

and subsequent reaction of decaborane with the appropriate acetylenic hydrocarbon to give the desired carborane derivative:

$$R\text{-}C \equiv CH + B_{10}H_{14} \longrightarrow \underset{B_{10}H_{10}}{\underset{\bigvee}{H\text{-}C = C\text{-}R}} + H_2$$

This process for converting decaborane to the desired carboranes was developed by MIRADCOM and scaled to a 20 gallon reactor size.

The other process is a **solvent/batch process** developed during the past four years by industry. This process involves the reaction of sodium borohydride with BF_3 etherate in solution to give decaborane:

$$NaBH_4 + BF_3 \text{ etherate} \longrightarrow B_{10}H_{14}$$

Both the pyrolysis and solvent/batch processes are viable, competitive processes for the preparation of decaborane.

Government Technology Transferred to Industry

In 1970, MIRADCOM began purchasing carborane in laboratory quantities from industry at $3000/lb. Since that

date, the purchase price has dropped to \$1400/lb. At the present time, industry capability does not exceed a few hundred pounds per year. MIRADCOM's need for large quantities of carborane at a more reasonable price prompted the Command to transfer the Government owned pyrolysis process to industry and to encourage industry to develop facilities to supply the Army's projected needs.

The technology basis for process improvements were carefully reviewed at MIRADCOM and verified by in-house laboratories where necessary. As a result of this review, MIRADCOM was convinced that the technology base was sound and that process improvements could be achieved that would result in a substantial cost savings. These estimated cost savings would far exceed the cost of the MM&T process demonstration studies. On this basis, an MM&T program was recommended and projects were initiated with industry to demonstrate the low cost production of carboranes.

Production Costs Tumble

The MM&T program—which is expected to cost ultimately about \$5.3 million—has demonstrated economic productivity of carborane using both the pyrolysis and solvent/batch processes.

Yields in excess of 65 percent compared with the present 30 percent were demonstrated for the diborane to decaborane pyrolysis process, and a 55 percent yield of carborane from decaborane compared with the earlier 40 percent yield. It is estimated that, based on these yields, carborane will cost \$300/lb or less compared with the projected \$800/lb prior to the MM&T process demonstration. This is an estimated saving of \$500/lb or \$15 million annually, based on a 30,000 lb/year production rate. The total MM&T investment should be recovered in about four months of plant operation. Similar calculations made on the solvent/batch process show that the total \$5.3 million MM&T investment would be recovered in less than six months.

Based on the demonstrated processes, a facility to produce carboranes in quantities up to 30,000 lb/yr is being designed and should be operational in January 1979. If availability of carboranes from this facility results in increased commercial demands, further cost reductions of \$30-70 per pound are projected. Such reductions would require larger plant investments and would only be cost effective if larger quantities are required.

Computer Simulation Feasible

In addition to the potential payback in cost savings from volume production, a simple, safe process for the production of carborane and carborane derivatives has been demonstrated. This process is briefly described following.

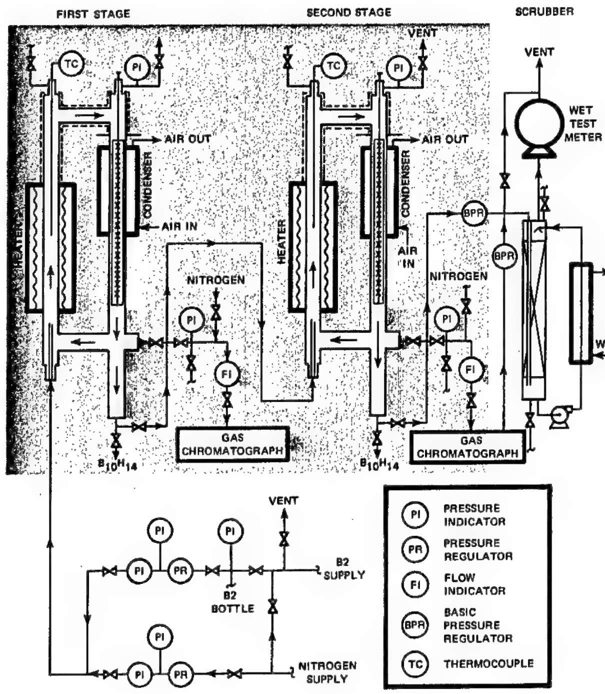

FIGURE 1

At the beginning of the present MM&T program, detailed review of previous experimental findings on pyrolytic conversion of diborane to decaborane identified the shortcomings of previous process concepts and led to the development of the present Convective Circulation Concept (3C) reactor. The 3C reactor (illustrated schematically in Figure 1) provides the necessary heat transfer and mass transport for effective diborane pyrolysis in a simple pipe loop, utilizing hot-cold gas density differences as the driving force for circulation. In this simple rectangular loop, fluid circulation is unidirectional, being alternately heated in the ascending leg and cooled in the descending leg. Superimposed on this internal convective circulation is the continuous diborane feed flow and removal of an off-gas stream of hydrogen, unconverted diborane, and volatile intermediates.

The 3C reactor has the additional advantage of being operated near atmospheric pressure, maintaining only sufficient pressure (2-3 psig) to prevent air leakage into the system in event of accidental failure. The 3C reactor is also amenable to mathematical analysis of fluid flow and heat transfer; thus, process optimization and scale-up have been aided significantly by computer simulation.

Demonstration studies employing the 3C reactor at significant scale have demonstrated both technical feasibility and high production yields. The proposed facility will be completed in approximately 24 months and will produce up to 30,000 lb/yr.

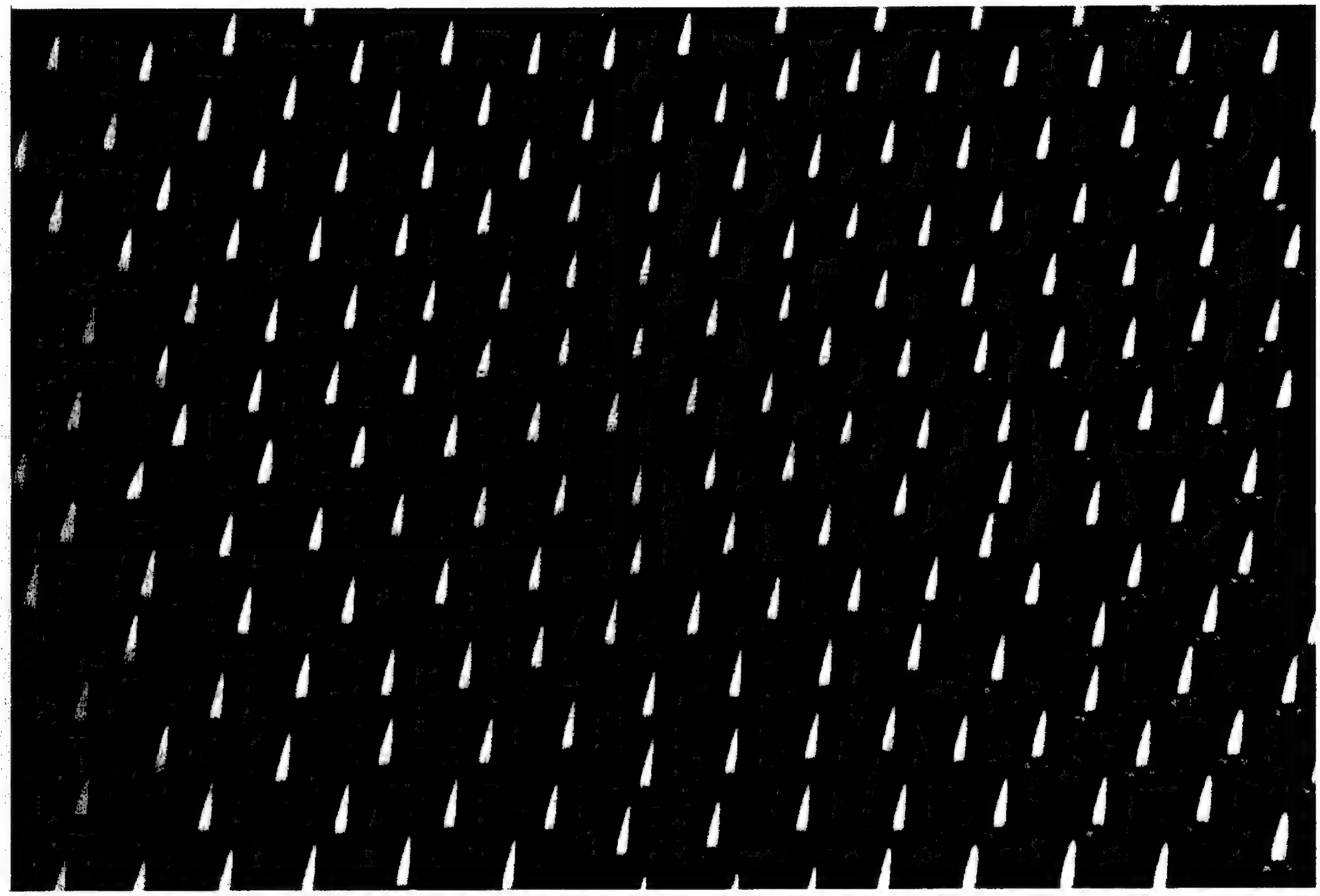

FIGURE 1 *1000X*

Level of Performance Unmatched

New Electronics Produced Faster

An investment of more than $1 million dollars since 1970 by MIRADCOM has paid off in a totally new electronic material that will improve performance of the electronics aboard not only missiles and in turbine components but also for many commercial items that must operate under extremely rough conditions or cold temperatures. Possessing structural and electronic properties unmatched by any previous material, the new development means a new level of performance can be designed into components of items depending upon reliable electronics gear.

The new class of material has been made commercially available through the efforts of the U.S. Army Missile Command's Manufacturing Methods and Technology Program. The material has been selected as one of the 100 most significant new technical products of 1976 by Industrial Research Magazine. The magazine sponsors the new products competition to recognize innovators and organizations for outstanding technical developments and to identify significant advances of interest to scientists and

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engineers. Oak Ridge National Laboratory and Georgia Institute of Technology jointly entered the material in the 100 products competition.

Unique Properties Inherent

Called metal oxide-eutectic composite, the material has unique structural properties that point to its potential use in many military and commercial applications. A major one is as a cold emitter—a solid state device operating without an internal heater as does a vacuum tube that can handle power requirements far beyond the range of the vacuum tube or transistor. Unlike either, it can withstand the rough service and extreme temperature that missiles and other military gear are subject to.

The structural properties also give the material potential for use in many applications where strength and toughness are required, as in turbine components. Its use as an electron emitting gun is also a possibility.

Academic Research Exploited

The Command's MM&T Program (through the Advanced Research Projects Agency Support Office) sponsored development of the material from a crude state to the present form in which both the material and the manufacturing techniques are available commercially. The Command established and financed the research and development program in 1970, in which Georgia Institute of Technology demonstrated that the material could be made to grow uniformly.

The multitude of problems faced in both the research phase and the development of manufacturing methods and techniques for the material can be seen from considering the physical requirements for multiple point field effect emitters. Each fiber must not only be of uniform size but must be essentially equally spaced from its nearest neighbors. In addition, the fibers must be capable of withstanding the high electrostatic forces present during field emission, the material cannot contain areas of missing fibers, and the fibers must be capable of withstanding the high braze temperatures associated with electron tube fabrication. Related problems included developing etching techniques capable of exposing and rounding fiber tips and developing braze materials and techniques compatible with the composite and support materials.

Manufacturing methods and techniques were developed that grow the material in an induction furnace by a process similar to that for growing crystal. It consists of an oxide containing more than one million parallel metal fibers in each square centimeter of material.

The fibers are uniformly spaced in the material and are essentially continuous along its length. The diameter of the fibers can be controlled by growth speed, and they can be grown from one micron to one tenth micron. The high growth temperature—above 2000 C—accounts for the stability and low vapor pressure of the material. The uniformly spaced fibers lend strength to the material much like steel rods placed in concrete (Figure 1). In an electronics application, electrons flow instantaneously from the tip of each fiber when the material is subjected to an electric field. These characteristics were predicted for the material by Army scientists and led to the initiation of the research and development program at Georgia Tech.

Superior Performance for Missile Electronics

One of the most promising applications to date for the material is for field effect electron emitters. For this application, the ends of the metal fibers are exposed by removing the oxide with an etch and then either rounding or pointing the exposed fiber ends. Since the field emitter is capable of producing a higher current density and requires no heater and ancillary equipment, it is an attractive replacement for thermionic emitters now used in high power electron tubes. In addition, the response time of the equipment is reduced to near zero; also, a field emitter made of this material is extremely rugged and can withstand extreme variations in temperature with essentially no change in electrical characteristics.

Follow-Up Project—New Uses

A second phase of the MM&T effort will provide for establishing production techniques for a low voltage field emitter assembly. This effort will make use of the material manufactured under the first phase of the program with shaped fiber tips and closely spaced control anodes such that the required operating voltages will be near that required for solid state devices. This assembly not only will extend the applications of field emitters for electronic devices, but will allow the design of new devices which will incorporate the best features of electron tubes and solid state devices.

Cable/ Harness Fabrication Automated

97% Labor Savings

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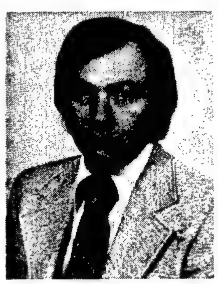


With labor savings as high as 300 percent apparently available, MIRADCOM is investigating the automation of electrical harness fabrication for missile systems. Preliminary cost surveys indicate that, under proper conditions, an automated operation will require less than 3 percent of the labor used in present manual operations. Based on concepts developed early in the program, Martin Marietta Aerospace is now engaged in the design, fabrication, and demonstration of a prototype facility. They will complete this effort in December 1977.

The concept for the prototype facility is based on a design using environmental type connectors and crimp style contacts. These connectors are finding increasing application in the missile industry and are more adaptable to mechanization than other styles. The concept involves presizing and termination of harness wires in a presequenced order; storage in sequence in a staging area; and finally, dispensing of the wires into a harness configuration.

Manual Assembly Still Practiced

This program arose from a fairly obvious need: Most operations in missile system production have been automated and improved considerably through the years, however, harness fabrication has advanced very little. Individual operators still manually assemble each harness on a tooling board for any production run—be it one or one thousand units.

Recognizing the potential for substantial cost savings, a study was launched in 1974 to examine harness fabrication processes, specifications, and restrictions. Ultimately, plans were formulated to develop concepts for automating the process and to demonstrate concept feasibility.

Incompatibility A Factor

An initial survey of manufacturing processes quickly demonstrated the lack of mechanized fabrication equipment. At the same time, the fundamental reasons for this failure to mechanize became apparent. As missile systems have advanced, the industry has developed an overwhelming variety of connectors and contacts, as well as processes for assembling harnesses. Obvious problems in automation arise because of the complexity of these systems. There is an even greater barrier, however—the majority of these items and processes simply are not compatible with mechanization.

On the other hand, it was found that environmental type connectors with crimp style contacts are gaining great favor in the industry and are found on more and more of the newer missiles. These connectors and the contracts—which can be soldered as well as crimped—are compatible with mechanized fabrication. Assuming the trend to use these parts will continue, MIRADCOM's development was based on this type of connector. To develop this concept, processes applicable to these connectors and contacts were studied in considerable depth. From this study, the prototype system was derived.

Fabrication Time Slashed

The study included a consideration of estimated costs. Production costs for the proposed concept were compared with those of manual processes. Using MTM (method time measurement) to establish fabrication times, total man-time, percent man-time, labor cost, percent labor cost, and percent span time were compared.

Potential savings were seen to be most significant. These savings, however, will be realized only if the harness design is compatible with mechanization and production quantities are sufficient to justify purchase of the mechanized equipment. Given a compatible design, optimum use of the mechanized concept, and constant labor rates, automatic fabrication will require less than 3 percent of the labor time and cost and less than 20 percent of the span time necessary for manual fabrication.

Prototype Under Development

Under the current effort, Martin Marietta is designing a full scale engineering prototype and, at the same time, they will demonstrate the feasibility of the facility. To do this, experimental runs will be made taking the wires through the sequencing and fabrication processes to a completed harness. During the runs, operating procedures will be developed, problem areas identified, and solutions derived.

The accompanying figure illustrates schematically the prototype facility as it is presently conceived. The wires will be cut to length and terminated in the machine shown at the center top. This operation has been programmed previously. The actual prototype operation begins with wire transfer and testing. This machine has a double conveyor, in which wires are accepted alternately. While one conveyor passes out one wire and receives the next, the other conveyor tests a third wire for continuity and termination crimp strength.

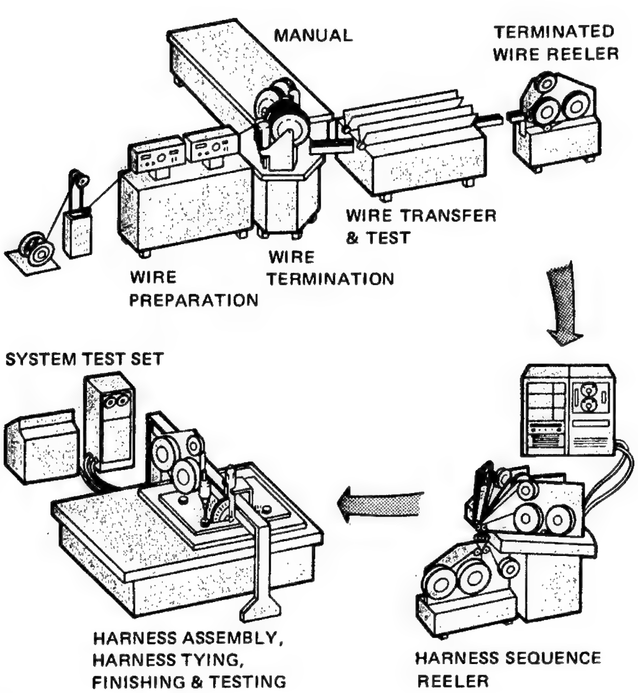


FIGURE 1

The conveyors pass the wires on to the terminated wire reeler, which will wind them onto a reel. This operation overcomes difficulties in controlling the wires at this point. They are stored on the reel in a continuous, channel shaped carrier with a cover liner on top of the channel to capture and enclose the wire in the channel. A simple control system starts the reel when a wire end is presented at the entry point, and the system stops it when the wire is completely wound.

One Gage of Wire Per Reel

Each reel accepts only one gage of wire. In order to provide the final harness sequence, these primary reels are processed on the reel-to-reel sequencer, which feeds them in a preprogrammed sequence to a secondary reel. This secondary reel goes to the insertion machine (not shown). On signal, this machine will unreel a wire and deliver the leading end to the insertion head, which will then insert and seat the wire into a connector. In the final prototype configuration, this machine will be the working head for a harness laying machine.

The harness laying machine includes the x-y table and a tooling board. On it, the wires are laid into guides with gates for retention according to a programmed configuration. Connectors are mounted to rotate transversely and swing into the harness axis after wire laying and insertion. The operation can be controlled either numerically or by minicomputer to (1) position each wire end over its proper connection (2) insert the wire contact (3) check it for seating (4) run the wire along its assigned harness path (5) insert the trailing end contact into its connector cavity and (6) test seating again.

Commercial Tying

The final operation is tying of the harness, which follows any manual operations necessary to complete unusual insertion. For tying, the connector rotates through a 90 degree angle into the horizontal plane of the harness and into its final position in the assembly. After dressing the wires, a commercial tying mechanism applies wrap ties. The tying head is programmed to place ties on the harness starting from the connectors and working toward the center.

The prototype facility is a simplified system that is not intended to fulfill all functions of a final production facility. But the machines will be full scale engineering modules capable of performing the basic operations for purposes of demonstration and analysis. An operational facility offering substantial cost savings should emerge—a facility that will function as an integral part of future weapons systems production.

Laser Seeker Cost Reduced

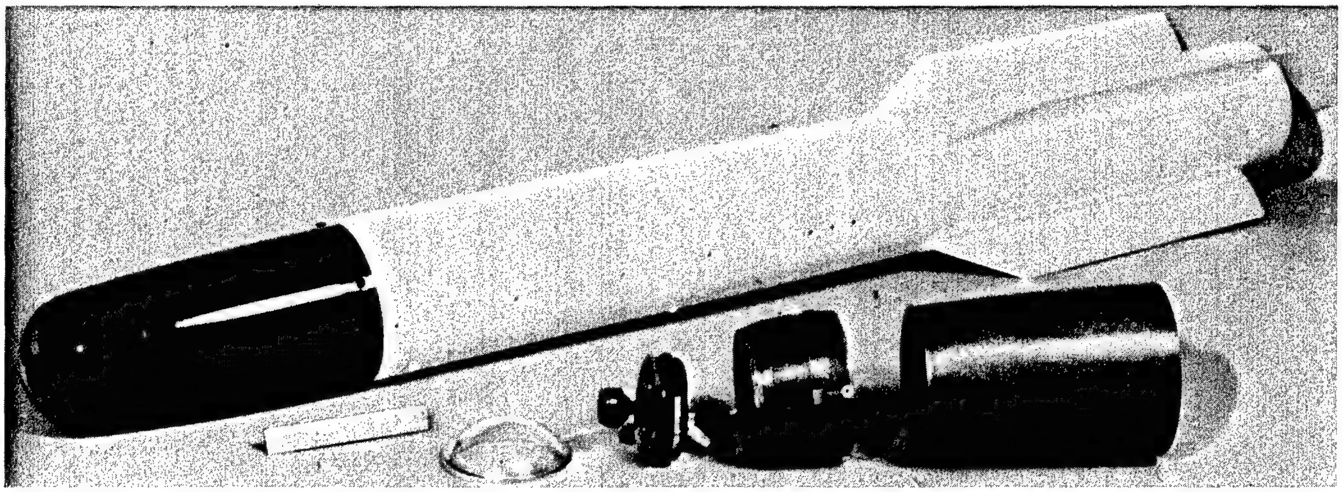


FIGURE 1

Major Fabrication Breakthrough

A major breakthrough in the manufacturing processes for laser homing seekers has brought at least a 20 percent reduction in their costs, following a MIRADCOM funded program. New processes for fabricating integrated head coils—also using injection molded plastic components in conjunction with a thorough review of all assembly techniques involved—are credited with the advance in this technology. Potential savings of $5 1/2 million are anticipated over the next five year procurement period.

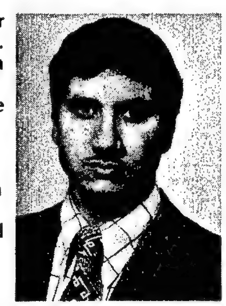
A Manufacturing Method and Technology program for Spinning Mass Terminal Homing Seekers was begun in June 1974 with Teledyne Brown Engineering. The objectives of the program were to reduce procurement lead time, reduce procurement cost, and provide state of the art production processes and techniques for production of laser terminal homing seekers. Most of the technology areas covered will be applicable to all spinning mass seekers, with special emphasis on HELLFIRE Seekers. The Army Laser Seeker (ALS) design (Figure 1) was selected for implementing the technology areas investigated in the program.

Multiple Technologies Addressed

The principal manufacturing technologies investigated included (1) injection molding of plastics for structural applications and for optical components, (2) head coil integration, (3) fabrication of spectral filters, (4) fabrication of magnets, (5) powder metallurgy, diecasting, and machining of gimbal and rotor components, (6) adhesive assembly techniques in place of threaded elements, and (7) less costly balancing, aligning, and focusing techniques.

The gimbal assembly, rotor assembly, detector integration, dome and spectral filter technologies were investigated during FY 76. All other MM&T tasks were completed prior to FY 76. Samples of all components and/or subassemblies were fabricated and evaluated during the year.

The various investigations and tradeoff materials and processes resulted in the MM&T seeker configuration illustrated in Figure 2. The MM&T seeker head production techniques include the use of gimbal potentiometers; a simplified head coil assembly; die cast aluminum gimbal/rotor structural parts; an injection molded dome,



CHARLES P. BAILEY is the Evaluation Director for the Army version of the Tri-Service Laser Seeker. He received his B.S. in Electrical Engineering as a Cooperative Student from Mississippi State University in 1972, and the Post Graduate Certificate on Sensor Technology from the University of Alabama, Huntsville, in 1976. Since joining the Advanced Sensors Directorate, U.S. Army MIRADCOM, Mr. Bailey has been affiliated with the COPPERHEAD, advanced and engineering development of the Tri-Service Laser Seeker, and was project engineer for the Spinning Mass Implemented Terminal Homing Seekers—Manufacturing Methods and Technology Program. Mr. Bailey's latter program has gained wide acclaim from both government agencies and industry. The Tri-Service Laser Seeker contractor is presently using two of the seeker heads for evaluation to determine how much of this new technology can be integrated into the TSLS; the COPPERHEAD contractor is also evaluating the seeker head, and MIRADCOM, through a contract with Teledyne Brown Engineering, is flight testing the seeker heads, which in this application are integrated with the baseline seeker.

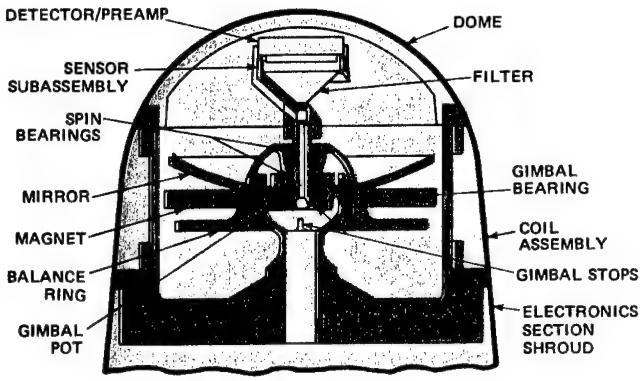


FIGURE 2

mirror, detector support, coil form, and electronics shroud/support structure; a segmented conical glass spectral filter; and a sandcast Alnico 5 magnet using adhesive assembly after grinding.

Cost Reduction Goal Achieved

The initial program goal was to reduce production cost of the ALS by 20 percent. This goal has been achieved. Manufacturing methods reports have been completed on each technology area investigated and have been distributed to each military service and to industry. The interest expressed by industry and the military indicates that many of the manufacturing materials and processes will be incorporated into future seeker systems.

Samples of seeker head assemblies using the suggested manufacturing processes and materials have been fabricated and subjected to limited testing to date. Further testing is planned in-house in FY 77 to validate the MM&T findings.

The information generated by the MM&T program has been distributed throughout the seeker industrial complex and appropriate Government agencies. Subsequent response has been good and demonstrates a strong desire by several contractors and government agencies to incorporate the technology into new seeker programs as well as ongoing programs.

The following items are a list of components whose processes and materials were developed during the MM&T Program and have been incorporated into the tri-service seeker.

- Injection molded plastic mirror with an evaporated gold coating for reflection (optics)
- Injection molded polycarbonate dome (optics)
- Injection molded plastic coil form/bulkhead (structural parts)
- Injection molded plastic shroud for the electronics section (structural parts)
- Injection molded plastic detector support post (detector part)
- Aluminum used for gimbal/rotor structural parts (gimbal/ rotor)

Complex One Piece Parts Used

In general, several precision machined stainless steel parts have been eliminated through the use of one piece complex structural plastic parts. This of course simplifies the subsequent assembly steps and reduces buildup of adverse dimensional tolerances.

Procedures developed for the MM&T seeker which currently are under consideration for incorporation into the tri-service seeker with the least interruption of the production line include

- Use of two inexpensive saturable reactors rather than four more expensive saturable reactors
- Use of low cost optical focus and alignment procedure
- Use of a segmented glass filter (cost of conical filter presently in use in tri-service seeker uncertain)
- Use of gimbal pots versus reference coils, caging coils, and caging cancellation coils (If the above is incorporated, the MM&T drive coil should also be incorporated.) The MM&T drive coil scheme would allow elimination of the mechanical cager.

A summary of the potential cost savings relative to the original ALS baseline seeker is given in Figure 3.

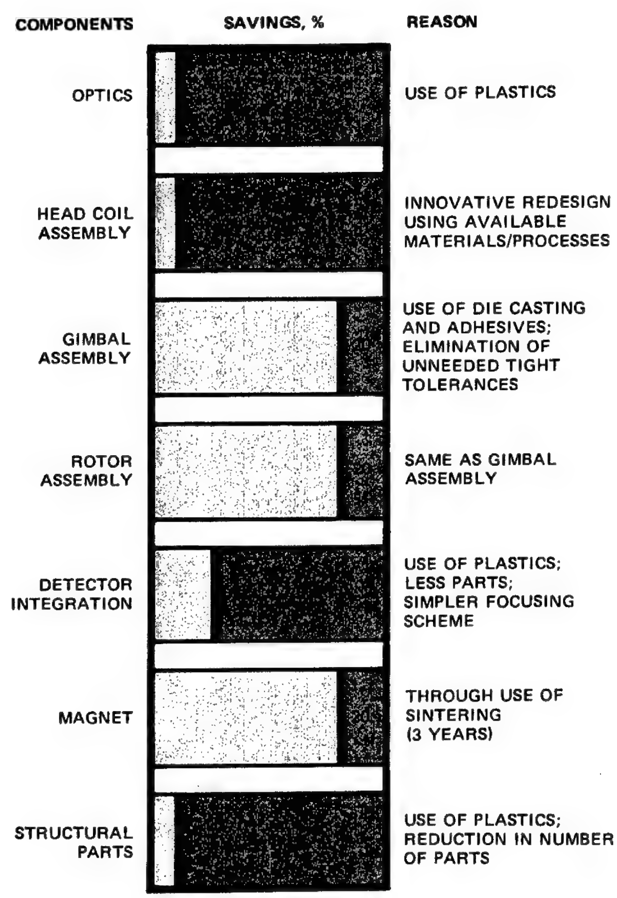


FIGURE 3

Unique NDT From Liquid Crystals

Encapsulation Brings Feasibility

BOBBY C. PARK is a Chemist in the Advanced Systems Development and Manufacturing Technology Directorate, MIRADCOM. Mr. Park received his A.B. Degree in Chemistry from Samford University. He was with Southern Research Institute for five years before coming to MIRADCOM, where he has been employed for the past 15 years. Mr. Park has authored and coauthored 15 papers.

Editor's note: Mr. Park was assisted in the preparation of this article on nondestructive testing by Ms. Shelba Brown, whose biographical notes and photograph accompany a preceding article on N-hexylcarborane production.

Using the unusual optical properties of liquid crystals, MIRADCOM has developed a new method for nondestructive testing of composite materials. This technique can also be used for nondestructive investigation of laminated structures, printed circuit boards, and other electronic components. Although the potential of liquid crystals for NDT applications has long been recognized, difficulties in handling them have precluded their use. MIRADCOM's method overcomes this problem by encapsulating the crystals in long, thin film. The technique is simple and reliable in comparison with present NDT methods and offers the potential of significant savings in time and cost.

This article describes research and development efforts related to the new technique. More specifically, it describes the development of liquid crystals; discusses MIRADCOM's adaptation of the unusual thermosensitive optical properties of cholesteric liquid crystals to nondestructive testing; describes the development of manufacturing techniques necessary to encapsulate and impregnate these compounds into cheap reusable films; and discusses potential applications of this technology.

Liquid Crystals Not New

The intriguing, confusing phenomenon known as the liquid crystalline state was discovered by Frederick Reinitzer, an Austrian botanist in 1888. Reinitzer heated cholesteryl benzoate and observed what appeared to be two meeting points. At 145 C the solid structure collapsed to form a turbid liquid, which, on further heating, became transparent at 179 C. This intermediate mesomorphic phase became known as the liquid crystalline state.

Liquid crystals are compounds that go through a transition phase that is intermediate between a solid and a liquid. A crystalline solid possesses definite volume and shape. Its molecules are arranged in definite geometrical configurations. The liquid state, on the other hand, is characterized by molecular mobility in three directions and a total lack of molecular orientation. Between these two clearly defined states, there are some crystalline organic substances that, over clearly defined temperature ranges, appear to possess the flow characteristics of a liquid while retaining much of the molecular orientation of the crystalline solid. This is the liquid crystal state first observed by Reinitzer. The relationship between these three states is illustrated in Figure 1. These phase changes are, of course, reversible. As the true liquid cools, it passes once again through the liquid crystal state before crystallizing into a true solid.

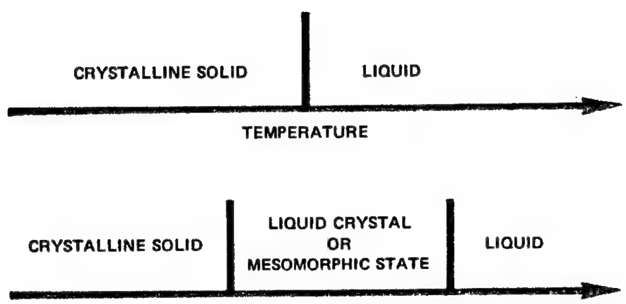


FIGURE 1

Many Compounds Fit Category

Liquid crystals are not as extraordinary as one might suppose. It is estimated that approximately one in every 200 organic compounds passes through this phase. The unique physical and chemical properties of liquid crystals, together with their wide occurrence in both inanimate and animate matter, make them valuable to chemists, biologists, physicists, and medical scientists.

There are three common designations of liquid crystals: smectic, nematic, or cholesteric. In the smectic configuration, molecules are oriented parallel to each other in well defined planes, somewhat like successive layers of honeycomb. In the nematic configuration, the molecules are also parallel, but they do not exhibit planar cohesion. The cholesteric state is similar to the nematic, but the molecules are helically displaced to a slight degree. A stack of library cards, each with one corner bent up, provides a simple model of the cholesteric state. The cards lie with flat surfaces parallel. However, the bent up corners cause a slight displacement or twist in the overall configuration. Since the derivatives of cholesterol, principally the esters, are important representatives of this configuration, the name "cholesteric" has been given to the entire class. Pure cholesterol does not act as a liquid crystal. Only its derivatives possess the unique optical properties applicable to the field of nondestructive testing.

Optical Characteristics Very Special

Some of the optical consequences of the molecular order of cholesteric crystals are:

- Birefringence. Birefringent materials transmit light waves at different velocities in different directions through the material. All liquid crystals are birefringent.
- Optical rotation. Optical rotation of polarized light occurs only in the cholesteric state. Cholesteric crystals are, in this respect, the most optically active substances known, since they rotate light through an angle several hundred times that of the usual optically active materials.
- Scattering of white light. White light is scattered to reflect different wavelengths, giving iridescent colors. Colors observed are a function of the specific cholesteric substance, the angle of reflected and incident radiation, and the temperature. This property allows the utilization of cholesteric crystals in visual inspection techniques. These materials are generally colorless on each side of the liquid crystal state—colorless, that is, in the true solid and the ultimate true liquid phase. Each cholesteric liquid crystal responds in its own way to changes in temperature. The change may be only from red to green, or from red through the entire color spectrum, or from green to blue. Each color corresponds to an exact temperature of the material being tested.

Encapsulation Means Dry Films

The unique properties of liquid crystals that make them valuable nondestructive testing tools are their sensitivity to thermal changes and their ability to respond to chemical impurities. Since liquid crystals reflect colors determined by the temperature of their environment, they may be used to project a visual, color picture of the transient temperature anomalies, or minute thermal gradients, associated with material discontinuities. These discontinuities, which may be failed bonds, cracks, or other defect areas, impede the flow of heat sufficiently to disturb the normal temperature patterns of a material being tested. The defects will show up as distinct color patterns because of their impaired thermal transmission characteristics. In like manner, color responses to chemical environments may be used for detection of flaws by interaction of the liquid crystals with chemical impurities concentrated in the defect area.

The physical problems involved in applying liquid crystal technology to nondestructive testing were resolved by encapsulating the crystals into reusable films. The

development of this manufacturing process is described in the following discussion.

Film Manufacturing Separate Project

The desired high temperature liquid crystal films were developed and manufactured by Westinghouse Laboratories, Pittsburgh, Pennsylvania, using MM&T funding. The purpose of this MM&T program was to establish and document manufacturing technology and processes to provide 3 foot wide continuous custom films containing a specific blend of liquid crystals, to be used up to 200 F in NDT applications. The application envisioned was the vacuum bag technique illustrated in Figure 2. It was necessary that these crystals be encapsulated for protection against handling and atmospheric attack, then coated onto a film with an absorbing black background for maximum color enhancement.

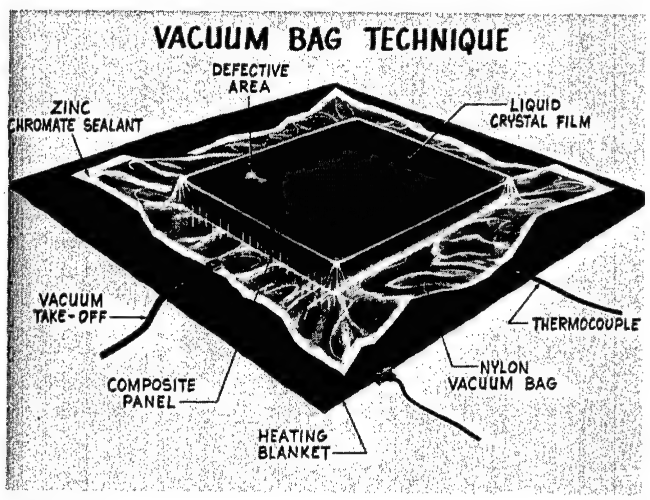


FIGURE 2

The specific custom blend of liquid crystals required consisted of 90 percent cholesteryl pelargonate and 10 percent cholesteryl myristate. Samples of the crystals were obtained from several suppliers and examined for temperature transitions and color response. Although the materials contained impurities, their transition points were reasonably close to those of the purified samples, therefore the color display temperatures of the purchased samples were also reasonably close. Because the liquid crystals will be used for thermography, as illustrated in Figure 3, it was decided to use them as received without further purification.

The encapsulants considered were to be soluble in solvents compatible with the liquid crystals. These solvents include aromatic and aliphatic hydrocarbons and chlorinated hydrocarbons. In all categories, the solvent should have a low enough boiling point to be evaporated without damage to the liquid crystal or support film and low enough vapor pressure so that it would not readily evaporate and affect the viscosity or the solids content of the coating solution. Some of the encapsulants tried are polyvinyl chloride, rubbers, silicones, and polyurethanes. Comparison of test results of butyl rubber and polyurethane can be seen in Figure 4.

Encapsulant Knife Coated

After evaluating these film forming candidates, the polyurethane encapsulating system was chosen for the

FIGURE 3

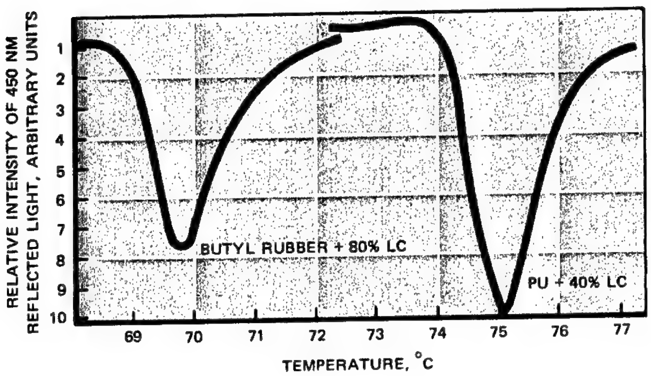


FIGURE 4

production run. The formulation for this system is:

1667 parts polyol (CNIS)
591 parts diisocyanate prepolymer (TU90)
1506 parts liquid crystal
2.2 parts catalyst
15060 parts toluene.

This formula provides a solution of 20 percent solids content, which is about optimum for casting a 0.001 inch coating. But the solution's viscosity is about 20 cp, which is too low for knife over roll coating.

To increase the viscosity from 20 cp to the 100-300 cp required for the knife over roll coating technique, a partial polymerization reaction between the polyol and the diisocyanate prepolymer was promoted. Part of the diisocyanate was reacted with all the polyol in a portion of the toluene until a viscosity of 300 cp was reached. The reaction was terminated and the remaining diisocyanate, together with the liquid crystal, dissolved in the remaining toluene to provide a coating solution of 150 cp.

The liquid crystal polyurethane solution was knife coated onto the clear polyester film at a coating speed of 3 ft/min and with a blade gap setting of 0.007 inch. After evaporation of the toluene, the remaining dry coating was about 0.0012 inch thick. The blackdyed polyester film was laminated to this using a heated laminating roll.

The finished product was a 1500 foot by 36 inch strip of encapsulated liquid crystal in a polyurethane matrix, laminated between polyester films—one of which was transparent and the other black. The liquid crystal was evenly distributed throughout the dry coating so that no discontinuities could be detected because of variation in the liquid crystal content. The laminate provided an even, intense color display between 71.5 and 72.1 C.

NDT of Large Items Now

Liquid crystals have had an enormous potential in the area of nondestructive testing for many years. This potential has not been realized because of the difficulties encountered in handling these greasy compounds. A dry, encapsulated liquid crystal film has now been produced which has the sensitivity and color intensity of liquid crystal and can be used in most applicationswhere liquid crystals are now employed.

The following composite structures have been investigated:

(1) Aluminum skins with HRP honeycomb core (HRP is high-temperature phenolic)
(2) Glass cloth skins with glass fiber honeycomb core
(3) Titanium skins with aluminum honeycomb core
(4) Titanium skins with HRP core
(5) Graphite/epoxy skins with HRP core
(6) Glass cloth laminates.

This nondestructive technique is readily adaptable to large hardware items such as rotor blades, fuselage panels, and other structures. This involves using large sheets of the impregnated liquid crystal film and systematically vacuum bagging and heating the surface from point to point until the whole structure has been inspected. Disadvantages of this technique are the need for vacuum bagging and the lack of a permanent record (other than photographs).

Significant NDT Role Predicted

The primary use of these films will be for NDT of missile components—i.e., composite wings, elevons, and electronic panels. These films should also be applicable for NDT or other Army metallic and nonmetallic structures such as helicopter blades, helicopter doors, airdrop pallets with honeycomb cushions, and circuit board checkouts. It is virtually impossible or extremely time consuming and expensive to nondestructively test some of these components. The establishment of a manufacturing technique for producing these new films permits the development of a new NDT technology that will play a significant role in the future reliability of missile systems. The simplicity and reliability of this system also will result in considerable time and cost savings.

Brief Status Reports

QUANTITY PRODUCTION TECHNIQUES FOR COMPOSITE ROCKET MOTOR COMPONENTS. The objective of this program will be met by five phases: Phase I—Establish automated manufacturing techniques. Phase II—Establish raw material requirements for automated techniques. Phase III—Establish equipment requirements for selected technology. Phase IV—Evaluate results for preparation of FY 76 program plan. Phase V—Prepare Project Report. The program has been completed except printing and distributing the final report. The one piece case concept was selected for a limited demonstration based on the manufacturing technology matrix trade charts. These components have been fabricated, tested and delivered. Contract DAAHO1-75-C-0416. For additional information, contact William S. Crownover, (205) 876-5821 or AUTOVON 746-5821.

COMPUTER AIDED SPECKLE COMPOSITE VOID DETECTION SYSTEM. The objective of this program will be met by work in five phases: Phase I—Comparison of speckle interferometric techniques. Phase II—Preliminary automated pattern recognition for correlation of fringe patterns and defects in composite materials. Phase III—Design a prototype interferometric video inspection and electronic processing system. Phase IV—Fabricate and test composite launch tubes and rocket motor cases with various controlled flaws or voids to demonstrate the feasibility of the inspection system. Phase V—A final report to cover progress to date. Flaws could be detected, located and measured using optical holography or Young's fringe speckle interferometry. Contract DAAHO3-75-A-0039. For additional information, contact Dr. Bobby R. Mullinix, (205) 876-5692 or AUTOVON 746-5692.

PROCESSING THIN WALL LARGE CERAMIC SHAPES. Work has been completed and a government technical report will be issued. It will describe all processing parameters the program established for fabricating full-size slip sprayed fused silica radome blanks. The Army's main benefit will be a standardized fabrication for the radomes by a new, more economical slip spraying process. Savings will be realized in two major areas of radome production: lower scrap rate and lower machining costs. An inorganic binder—colloidal silica—used in the slip spraying process yields a radome preform with significantly higher green strength than a slip casting. The unfired radome can be readily handled without warping or cracking. Its high green strength also prevents cracking during the drying cycle, a serious problem with slip cast radomes. For additional information, contact F. Meyer, G. Harris, Army Materials and Mechanics Research Center, ATTN: DRXMREO, Watertown, Ma. 02172, (617)923-3365/3258 or AUTOVON 955-3365/3258.

IMPROVED MANUFACTURING PROCESSES FOR SILICON VIDICONS. Performance and production techniques applicable to reduced blooming silicon target vidicons were reviewed and analyzed. The process and manufacturing plan will be updated to form the description of manufacture. A screening and evaluation process for the silicon target was devised and implemented. Materials were acquired and a sample production lot of tubes was fabricated. The process and manufacturing plan will be revised as necessary, pending the results of the tube testing and evaluation. Contract DAAHO1-76-C-0996. For further information, contact E. D. Crosswhite, (205) 876-2922 or AUTOVON 746-2922.

MANUFACTURING TECHNIQUES FOR STATIC SWITCHES. The packaging concept was finalized. The switch will be a single flexible circuit to which all components and assemblies are mounted. Transformers and associated capacitors, mounted on two separate subassemblies, will be mounted to the flexible circuit along with the hybrid circuit, load/arm switch, input/output connector, and the voltage regulation circuit. After component assembly, the flexible circuit is folded and assembled onto a support, then inserted into a shell and encapsulated. Package documentation is completed and that for the hybrid circuit production is in processing. Future work includes: (1) completing the static switch packaging effort, (2) completing the hybrid circuit effort and starting production, (3) fabricating hybrid test equipment and, (4) testing production prototype switches for low temperature operation and induced noise. For additional information, contact J. D. Saunders, (205) 876-3681 or AUTOVON 746-3681.

LOW COST PRODUCTION METHOD FOR HANDLING HYBRID CHIP VIA A TAPE CARRIER LEAD FRAME. TCLF industry survey questionnaires are being reviewed. Preliminary examinations indicate that the most cost effective application of TCLF technology would be multichip hybrids. The completed TCLF cost analysis included the development of cost models for automatic TCLF assembly and conventional chip and wire assembly. Substrate manufacturing specifications (including thick and thin film applications) are being developed. Completion date of this specification may shift to later in the program. Contract DAAH-01-76-C-1079. For additional information, contact Jake Herron, Jr., (205) 876-3834 or AUTOVON 746-3834.

PRODUCTION METHODS FOR MOUNTING NONAXIAL LEAD COMPONENTS. Component manufacturers have been surveyed and automatic insertion of components in printed circuit boards has been analyzed. Military type metal can transistors and double inline plastic mounted devices are 60% of those used in printed boards. Nonaxial lead devices can be machine inserted economically, but the least expensive insertion is by pantograph. Improvements in automatic insertion (such as machine identifying part number and part orientation) being explored will substantially reduce incorrect insertion. Insertion tooling is being developed. Factors leading to incorrect insertion are being identified, and methods of improving percentages of correct insertion are being devised. Optical methods of reading part numbers and orientation are of primary concern; means of straightening leads to required tolerance are being developed. Upon development of viable solutions to the many problems of insertion, a demonstrator will be constructed. For additional information, contact R. L. Brown, (205) 876-4885 or AUTOVON 746-4885.

NONDESTRUCTIVE TESTING TECHNIQUES FOR COMPOSITE ROCKET MOTOR COMPONENTS. This program's objective was met by work in four phases: Phase I—Full-scale rocket motor component demonstration utilizing FY74 results. Phase II—Production demonstration for selected components. Phase III—Develop data for specifications on the selected technique. Phase IV—Final project report. The system is capable of inspecting at least one complete inner case and propellant grain every minute and one assembled rocket motor every thirty seconds. The system is a reliable production methodology to eliminate faulty motors at a nominal cost. With minor modifications, it could be used for nonhazardous hardware inspection. Contract DAAHO1-74-C-0564. For additional information, contact William S. Crownover, (205)876-5821 or AUTOVON 746-5821.

ADDITIVE PROCESSES FOR FABRICATION OF PRINTED CIRCUIT BOARDS. In selecting candidate processes, peel strength before and after solder float became the crucial test; two candidate semiadditive processes have exceeded peel strength requirements of MIL-P-13949 and MIL-P-55617. Either process can produce printed wiring boards with circuit densities much higher than possible with substrative methods. The major effort will be toward semiadditive processes showing the highest peel strength; minor effort will be on process variation to determine if candidates failing peel strength tests by narrow margins can be upgraded. Contract DAAHO1-76-C-1100. For additional information, contact Mr. R. L. Brown, (205) 876-4885 or AUTOVON 746-4885.

COMPUTERIZED PRODUCTION PROCESS PLANNING. This pilot project is to demonstrate generation of process plans for machined cylindrical parts using a Computerized Production Process Planning (CPPP) system. The part proposed is a nitralloy sleeve belonging to a part family for the G. E. T700 engine. The part family is of such a complexity that manufactured components can require up to forty operations. This project includes a cost benefit analysis of various levels of computerized production process planning for cylindrical and noncylindrical machined parts. Contract DAAHO1-76-C-1104. For additional information, contact R. A. Kotler, (205) 876-3777 or AUTOVON 746-3777.

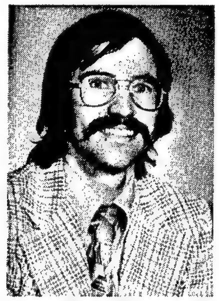
FLUIDICS MANUFACTURING AND ASSEMBLY PROCESSES. An in-house effort evaluated fluidic device photographic masters and fabricated the unit in stainless steel. On the MM&T effort the contractor: (1) Converted the photographic master artwork from compensation for stainless steel to compensation for aluminum, (2) Completed the photo tools for etching the aluminum planes, (3) Reduced the aluminum planes required per PDM by using 30-mil instead of 10-mil foil for manifolds, (4) Defined the etch process for accurately etching planes containing active elements (4 and 10-mil) and manifold planes (30 mil) to reduce time and cost, (5) Designed the etcher and is fabricating it, (6) Generated the inspection plan and is acquiring the equipment, and (7) Investigated bonding with and without an aid. For additional information, contact James G. Williams, (205) 876-5323 or AUTOVON 746-5323.

PROCESSING OF LASER OPTICAL CERAMICS. Efforts were concentrated on scaling up the size of the Nd:YAG single crystals. Initial ingots were 5-cm diam, 2.7 cm high, and 250 g. Next, ingots 7.5-cm diam, 5 cm high, and 1000 g were grown. Current scale-up efforts are yielding 7.5-cm diam, 6.4 cm high, 1300-g crystals. Future work includes: (1) Designing and installing a heating element in the crystal growth furnace. (2) Growing Nd:YAG single crystals 7.5-cm diam, 7.5 cm high, 1585 g. (3) Controlling melt stoichiometry to eliminate scattering centers in the crystals. (4) Producing laser quality 7.5-cm diam, 7.5-cm high, 1585 g crystals. For additional information, contact Dennis J. Viechnicki or Jarda Caslavsky, Army Materials and Mechanics Research Center, Watertown, Ma. 02172, (617) 923-3463/3352 or AUTOVON 955-3463/3352.

AN ACOUSTICAL HOLOGRAPHIC PASSIVE NONDESTRUCTIVE TESTING TECHNIQUE FOR CERAMIC RADOMES. The objective of this program will be met by work in five phases: Phase I—Detection, location, and determination of the sizes of various types of voids in laboratory samples. Phase II—Correlation of acoustical data with X-ray and other NDT techniques. Phase III—Selection and fabrication of laboratory models. Phase IV—Evaluation of the acoustical system to detect manufacturing defects in thick walled composite structures. Phase V—Preparation of the final report. The acoustical system using the array technique easily detected the flaws and voids. For additional information contact Dr. Bobby R. Mullinix, (205) 876-5692 or AUTOVON 746-5692.

Survival At Less Cost

New Look for 'Copter MM&T



ROGER L. SPANGENBERG is an honor graduate in Aerospace Engineering of the University of Maryland and holds a Master's Degree in Industrial Engineering from Texas A&M University. He is also a graduate of the U.S. Army Engineering Intern Training Center in Product/Production Design Engineering. Mr. Spangenberg has spent five years with the Department of the Army in both technical and management capacities. At the U.S. Army Aviation Systems Command, he was project engineer for the development of advanced manufacturing technology for production of engine and airframe components used in Army helicopters. While at AVSCOM he also served as the Command's Computer Aided Manufacturing coordinator. In his present position at the U.S. Army Tank Automotive Command, Mr. Spangenberg is responsible for management of planning and programming for the XM-1 Tank Development. He is a member of the Tau Beta Pi, Sigma Gamma Tau, and Alpha Pi Mu honor fraternities, and he is a member of the AIAA and SAMPE technical societies.

Editor's note: This series of articles was written by Mr. Spangenberg while he was with the production Technology Branch at AVSCOM. Since completing the articles, he has assumed a new position with the U.S. Army Tank Automotive Research and Development Command. Readers wishing to acquire more information about AVSCOM's helicopter manufacturing technology program may contact Mr. Gerald Gorline or Mr. John Stanfield at (314) 268-6476 or AUTOVON 698-6476.

Part 1: Airframe and Rotor System Technology

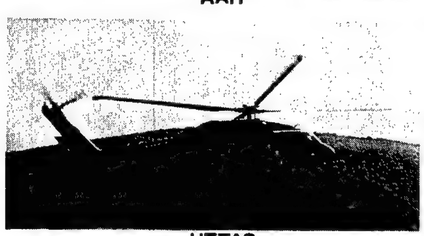
Automated assembly techniques—advanced bonding and forming processes—improved design—new composite structures and other advanced materials. These all reflect Aviation Systems Command innovations in helicopter manufacturing technology. Technology that is being applied to today's Army helicopters. Technology that will be applied to tomorrow's Army helicopters. Technology that will allow marked cost reductions.

Over the past 10 years, helicopter manufacturing technology has advanced rapidly. But much room for further advancement remains as the technology base steadily broadens. And all the while, the need to improve manufacturing processes grows in importance as costs spiral.

Unit Costs Jump

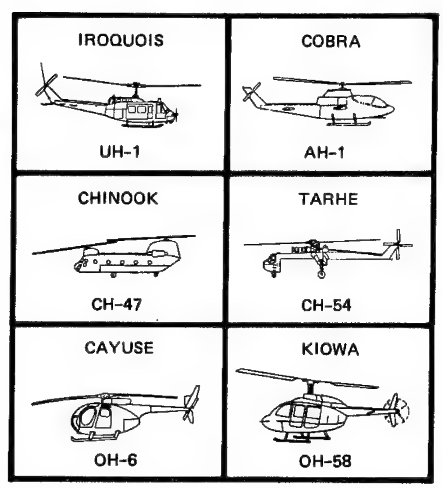
For example, consider the new helicopters soon to enter the Army inventory. Both the Advanced Attack Helicopter (AAH) and the Utility Tactical Transport Aircraft System (UTTAS) have been under development for several years—the former at Bell and Hughes, the latter at Boeing-Vertol and Sikorsky. (Hughes and Sikorsky were winners of the development competition.) These helicopters outperform previous models, representing the latest state of the art in manufacturing technology. They also will cost substantially more than previous models. Flyaway costs are about $1.9 million for the AAH and about $1.1 million for the UTTAS.

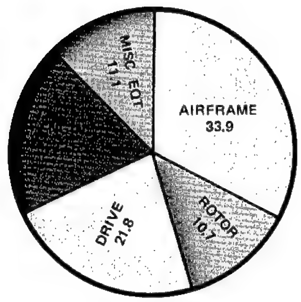
AAH



UTTAS

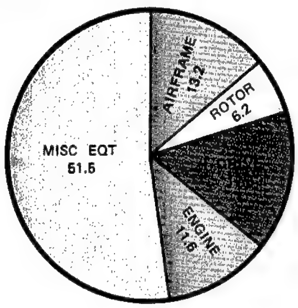
Considering these costs, the next several years present a severe challenge to both government and industry. We must develop and implement new manufacturing technologies both to reduce costs and to en-





UTTAS

ESTIMATED RECURRING PRODUCTION COST DISTRIBUTIONS.



AAH

sure effective producibility. Areas for further advancement include the airframe, rotor system, drive system, and engine systems, which are being looked at for new technology advances and cost reductions. This article discusses the first two; the airframe in particular is most important to the cost picture.

Airframe Technology Tied to Survivability/ Labor Costs

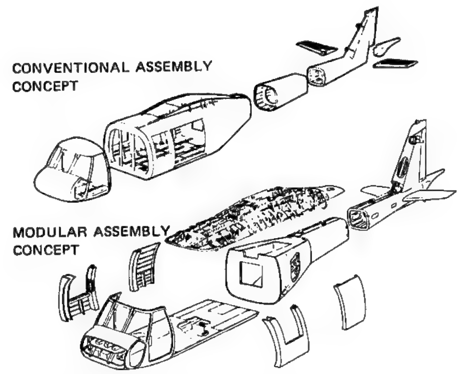
The conventional semimonocoque helicopter airframe usually consists of aluminum alloy skins riveted over formed aluminum stringers and forged aluminum frames and bulkheads. These airframes normally utilize titanium and stainless steel only for such components as firewalls and fittings. Many designs call for bonded structures for flooring and secondary structures such as doors and fairings. For these secondary structures, designers are using aluminum, Nomex (a nonmetallic cellular stiffener), or foam honeycomb, and, to an increasing extent, fiberglass and other composites.

Survivability features have become increasingly important in recent years and have strongly influenced helicopter design and construction. Of helicopter manufacturing technology program expenditures over the past 10 years, about 25 percent has gone into airframe technology. Programs aimed at producibility of components to ensure survivability have consumed a significant portion of these funds.

Reduction of labor costs has been a primary goal in the improvement of airframe manufacturing technology. Labor accounts for about 89 percent of airframe recurring production costs, with about 70 percent of that labor applied to assembly operations. Contractors have shown great initiative in introducing manufacturing improvements to reduce labor costs.

Modules Reduce Assembly Costs

One approach that helicopter companies have followed is modu-



larization of assembly operations. In this approach, assemblers equip each module with its own hydraulics, electronics, and other equipment before joining the separate modules. This allows more efficient use of assemblers. Boeing-Vertol estimated that 90 percent of UTTAS assembly operations would be on modules and that this would produce a 10 percent saving in total assembly man-hours.

Helicopter companies also have introduced automatic riveting of airframe structures. Automatic techniques can account for as much as a 75 percent reduction in riveting costs.

In further cost-reduction programs, many companies have incorporated numerically controlled drafting and machining operations into airframe assembly. Computer usage throughout the design and manufacturing phases is expanding rapidly.

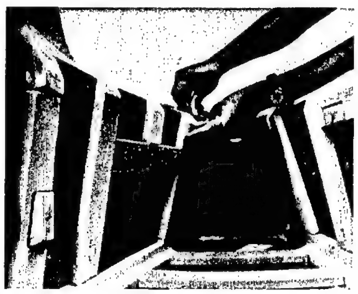
Two Army manufacturing technology efforts in conjunction with Hughes Helicopters have significantly reduced costs of secondary structures—more efficient composites fabrication and ultrasonic welding.

Composites Become Producible

Composite materials offer strong potential for cost and weight savings in fabrication of secondary structures; on the other hand, they require excessive hand labor and lengthy curing cycles—decided drawbacks to their use. These disadvantages have been overcome in one of the programs with Hughes.

The construction phases of the engine inlet aft fairing for the Hughes OH-6 helicopter required time-consuming hand layup involving emplacement of a large number of specially sized foam blocks between fiberglass skins. In addition, the

Outer Skin

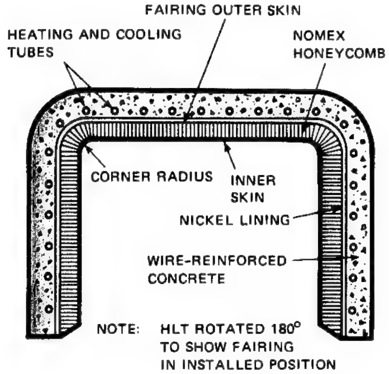


Inserts

Inner Skin

operation required three cure cycles—the first and third being two hours in a 275 F oven, while the second took place under heat lamps for a one-hour period.

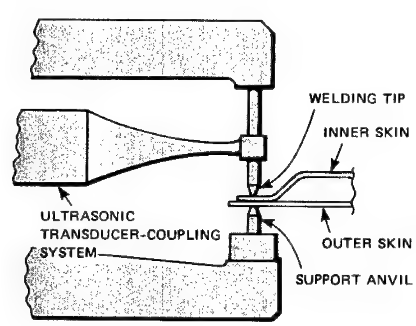
Because this operation was so costly, Hughes took a close look and developed a low-cost, low-leadtime mold, based on some of their previous work. The female mold shown forms the outer contour of the fairing. The cavity of the mold is lined with an electrodeposited nickel skin which is backed up by wire reinforced concrete imbedded with copper tubes. The tubes circulate either steam or cold water to cure or cool the composite structure, and the nickel liner gives the mold a hard, smooth surface into which the composite pieces are laid.



The fairing shown was redesigned for fabrication by this tool, with inner and outer skins of the new fairing containing a core of Nomex honeycomb to replace the numerous foam blocks of the previous construction. The use of integrally heated tooling reduces assembly man-hours from 32.2 to 10 also saves on energy, tooling, and space/facilities. Based upon production of 250 units per year, $115,000 is saved. Hughes has used similar equipment for production of other such fairings, resulting in additional benefits.

Ultrasonic Welding Another Labor Saver

In another manufacturing technology program sponsored at Hughes, AVSCOM currently is seeking to apply ultrasonic welding to airframe structures. This program is under a contract to the Sonobond Corporation, which is working in conjunction with Hughes. Ultrasonic welding converts electrical power to mechanical vibratory power by means of a transducer coupling system, with the vibrations delivered to the part being welded. This induces dynamic



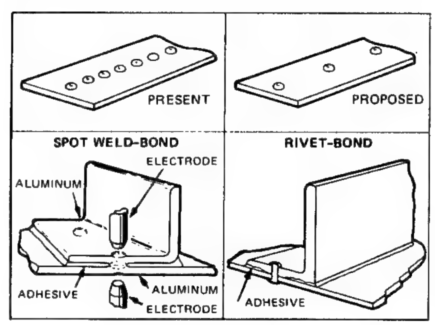
stresses in the material, resulting in local plastic deformation of the material interface. The deformation breaks up surface films and oxide layers, promoting a solid state metallurgical bond. Because there is no melting in the weld zone, problems inherent in resistance welding (and discussed later) are overcome. Since the surface films are broken up, the cleanliness required in adhesive bonding is not necessary.

Upon completion of process development, Hughes first will use ultrasonic welding on structures such as doors; this application will produce a 75 percent or more reduction in the man-hours previously required for bonding and also will eliminate fasteners and the labor to install them. The technique later will be extended to primary airframe structures.

Bonding Replaces Fasteners

Other approaches to fastener technology are also noteworthy. Since a large helicopter contains over 5,000 fasteners of various types and sizes, intense installation labor is necessary; this has brought serious efforts to reduce the number of fasteners used. That labor accounts for the fact that over half of an airframe's direct support maintenance cost presently is related to fasteners and secondary structures.

Automatic riveting has already been mentioned; two other methods—spot weld bonding and



rivet bonding—can provide dramatic improvements over conventional rivet construction, but there are drawbacks. Resistance spot welded parts undergo melting in the weld zone, which can result in wrinkling when the pieces are clamped. Also, the recast metal in the area of the weld is susceptible to fatigue; and a breakdown in adhesive on weld bonded parts can create porosity in the weld nugget. Rivet bonding decreases the number of rivets, but does not eliminate them. Also, bond-

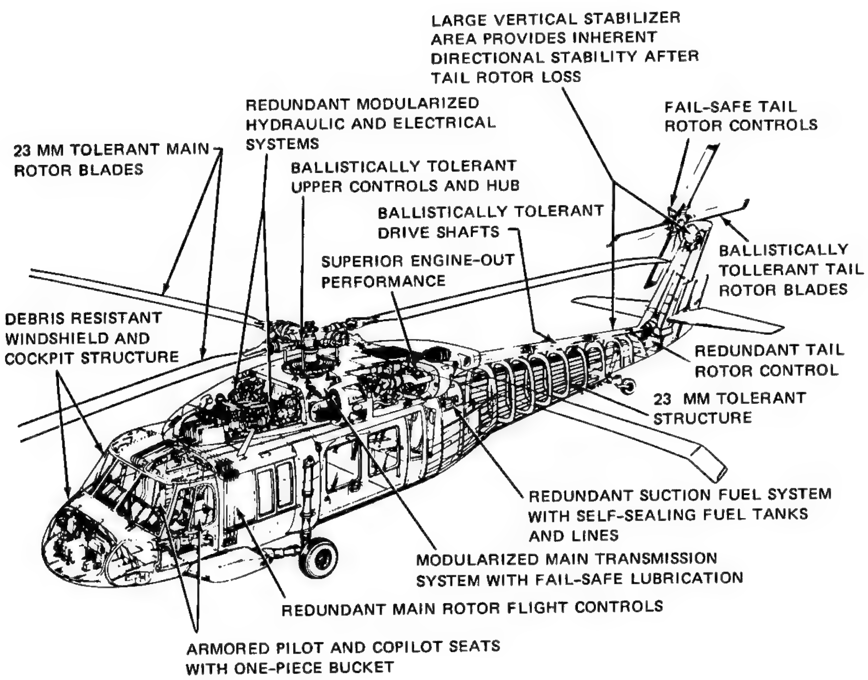
ing operations require cleaning and degreasing of the surfaces.

Some other airframe manufacturing improvements that AVSCOM has sponsored over the past several years include:

- Welding processes for titanium sheet alloy
- Production techniques for aluminum powder metallurgy components
- Application of computer-aided manufacturing techniques to the extrusion of airframe structural members.

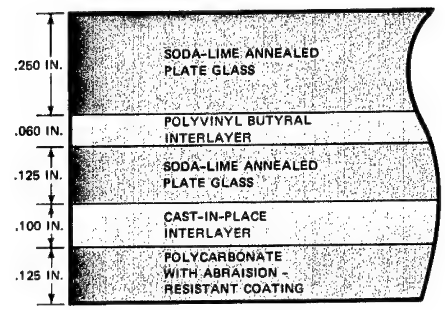
Airframe Components Another Target

Manufacturing technology improvements are being applied not only to airframe assembly operations but to production of airframe components as well. For example, the survivability and safety features incorporated on the Boeing-Vertol and the



Sikorsky UTTAS are made possible through use of new materials and structures. These new materials and structures have required new manufacturing methods, which are results from AVSCOM's manufacturing technology program.

Windshields and windows on current Army helicopters are usually made from stretched acrylic, which offers little ballistic protection. However, recent advances in transparent armor technology make these materials attractive for use on future Army helicopters. For example, in a project for the Army Materials and Mechanics Research Center, Goodyear Aerospace developed techniques for producing a new laminated glass/plastic composite armor which provides ballistic protection equal to thicker, heavier transparent armor previously used.



This armor system protects against projectiles and fragments without spall particles typical of most windshields. Goodyear has developed production techniques for transparent armor windshields identical to the nonarmored windshield currently in the UH-1. In addition, Goodyear has performed extensive ballistic, environmental, optical, and flight testing to make sure that these windshields meet Government specifications.

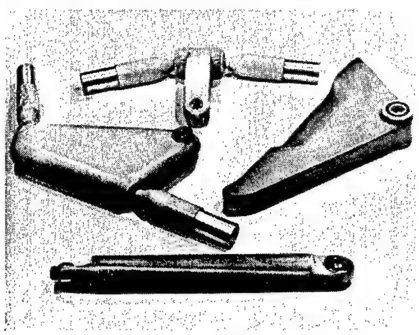
One major problem remains with this potential application. Because of contour variances brought about during the gravity bending of the plate glass, each piece of contoured armor requires its own production tooling, resulting in prohibitive costs. However, for flat panels the glass/ plastic armor produced is inexpensive enough to be used.

In another application, laminated transparent armor panels of similar composition have been placed between the fore and aft members of the AAH. This reduces the chance of both the pilot and copilot being hit simultaneously. The reproduction technology developed under the MM&T program made selection of this type of armor practical.

Flight Control Components Critical

Survivability also involves protection of the flight controls since approximately 35 percent of the helicopter losses in Vietnam resulted from hits on these components. Consequently, attention has been given to improving the survivability of control systems, which normally consist of a large number of bellcranks, links, U-joints, and push-pull tubes.

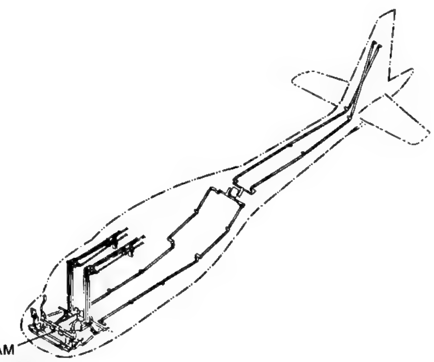
Such components usually are made from either aluminum or magnesium; however, U.S. Army Air Mobility Research and Development Laboratory contractors are producing a variety of fiberglass flight control components that resist ballistic damage. These newly designed com-



ponents had previously been made only on a prototype basis; their manufacturing cost, weight, and reproducibility exceeded those of conventional metallic components. Manufacturing technology was initiated to develop capability for producing flightworthy components at a high rate for comparable cost.

Low-cost fabrication techniques considered in these programs have included filament winding, broadgoods and tape layup, compression molding of epoxy bulk compound, and pultrusion (described on the last page of this article). Specific components have been redesigned to accommodate the processes employed. Results thus far show that selected components can be competitive with metallic components in cost and weight and can provide the desired damage tolerance.

Most of the upcoming generation of helicopters already have been designed with redundant metallic flight controls; however, one manufacturer is currently considering a change to fiberglass components.



As manufacturing methods and designs are further refined, replacement of redundant controls with ballistically tolerant composite components can be anticipated.

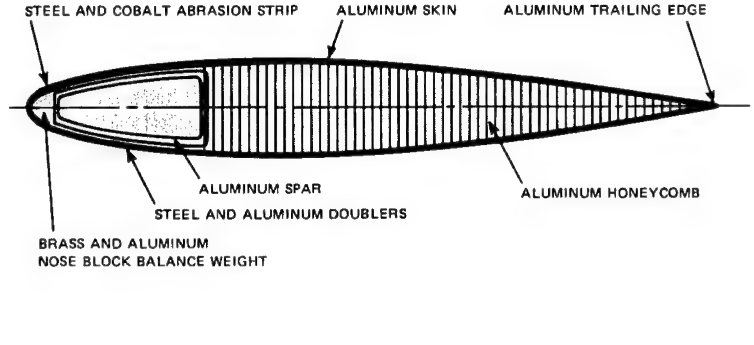
Ceramics Used

Other airframe component manufacturing technology efforts through the years include development of:

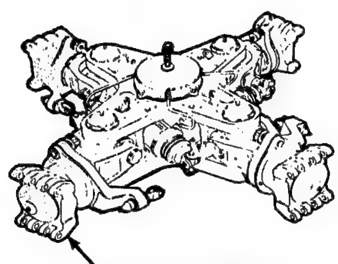
- Techniques to manufacture scratch and spall resistant windshields
- Transparent armor for applications other than those mentioned and for other ballistic threats
- Ceramic armor for seats and for panels to protect the cockpit.

Rotor Blade Designs and Materials Considered

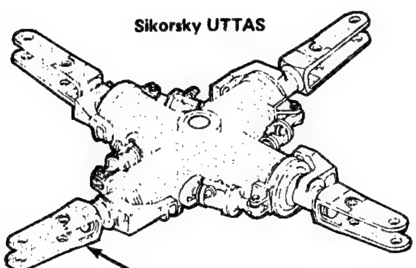
Helicopter manufacturing technology efforts have not been confined to the airframe; rotor blades are among other components that have been given considerable attention. Rotor blades on current Army helicopters basically are all-metal structures joined by adhesive bonding. They usually are composed of machined aluminum honeycomb, with either steel or aluminum spars and doublers formed or extruded and



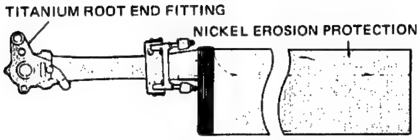
Conventional



Fold Hinge Attaches To Similar Fitting On Blade (Cuff)



Single Combined Fold Hinge-Cuff Attaches Directly To Blade Spar



machined to shape, and covered with aluminum skins. The UH-1H blade is typical of conventional structure.

During recent years, rotor blade designers have used composites on a limited basis. In the upcoming generation of helicopters, however, composites will be used far more extensively, together with titanium, steel, and Nomex nonmetallic honeycomb or aluminum honeycomb.

Attention has also been given to rotor heads. A conventional assembly consists of a number of bearings, hinges, and actuators. The newer designs, on the other hand, utilize titanium hubs with elastomeric bearings; they have fewer parts (40 percent in the example shown); and they are lighter, more reliable, and less expensive.

Recent manufacturing improvements sponsored under the AVSCOM manufacturing technology program have emphasized economical methods of producing metallic components for the rotor systems of the new generation of helicopters. Particular attention has been paid to utilizing improved materials and shortening fabrication operations.

Flight Performance Increased

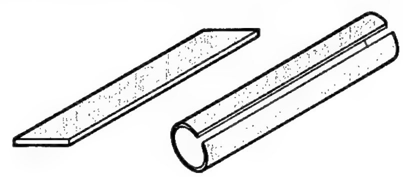
The application of composite materials to rotor blades has allowed significant performance improvements. Composite blades are tailored to aerodynamic shapes previously not possible, resulting in production blades with varying twists and cross sections. Manufacturing technology efforts have emphasized processes to transform new designs utilizing composite materials into components that are producible.

As an example of this technology, the rotor blade on the Boeing-Vertol UTTAS includes a Nomex honeycomb core, fiberglass skins and spar, and a formed titanium leading edge. The leading edge is nickel plated on the outboard section for abrasion protection.

Titanium Scrap Loss Prevented

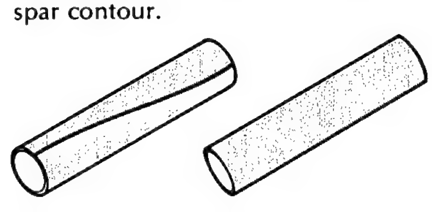
In other blades, such as that for the Sikorsky UTTAS, the spar is made of titanium, which was initially machined from a 3400-pound extrusion. The finished part represented only about 10 percent of the original weight, and this excessive chip removal made production costs prohibitive. Sikorsky's efforts, both independent and under current manufacturing technology contracts, reduces fabricating costs of this spar by $10,000 while saving over 90 percent of the titanium scrap loss.

In the manufacturing steps in the new process, titanium plate stock weighing only 250 pounds is cold brake formed into a cylindrical shape



FLAT STOCK BRAKE FORM

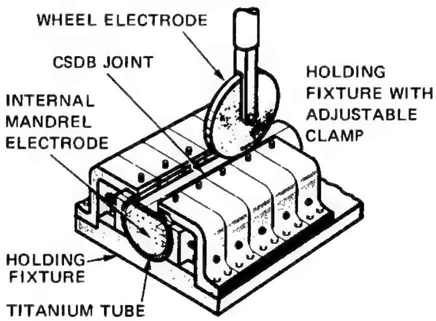
with a close fitting spanwise opening. The slit cylinder is then joined by either welding or diffusion bonding, then the tube is formed between hot ceramic dies to obtain the required spar contour.



JOIN FORM

Welding Procedures Simplified

Another AVSCOM manufacturing technology effort resulted in the continuous seam diffusion bonding process, a concept of the Solar Division of International Harvester that eliminates costly and time consuming control of an inert gas atmosphere inherent in joining procedures such as plasma arc welding. The process consistently produces bonds with base metal strength and does



not require extensive hand finishing of joints.

Sikorsky already utilizes tube joining methods to produce rotor blades for the CH-53 helicopter. At the conclusion of the present manufacturing technology effort, it is anticipated that the continuous seam diffusion bonding process will be applied directly to Sikorsky UTTAS production. Other military helicopters should also benefit from use of the process.

Rotor blade manufacturing has seen other process improvements over the past several years:

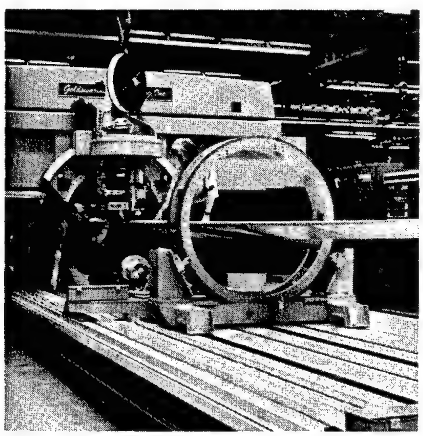
- Techniques to decrease machining requirements for large titanium rotor hubs by producing them in pieces and diffusion bonding the pieces together.
- Techniques to economically coat titanium nose caps with a ceramic to replace the lengthy (12–16 hour) nickel electroforming process.

Automated Layup Boosts Composite Production

The use of composites in helicopter rotor blades began about 10 years ago. The AVSCOM manufacturing technology program has been instrumental from the beginning in the development of techniques to produce them. The ability to form fiberglass into complex contours has allowed designs that are uncompromised by constraints of the manufacturing process. On the other hand, this capability is based upon manually laying up alternate layers of fiberglass and epoxy resins. The resulting components have been expensive, time consuming to produce, and of variable quality—characteristics unacceptable on a full scale production basis. Consequently, in 1967 Boeing-Vertol began a corporate effort to develop a better method of composite forming. After considerable work, the contractor was able to recommend to AVSCOM an automated process for full scale production of composite rotor blades.

After a small study to demonstrate feasibility, AVSCOM awarded a contract to Boeing-Vertol and Goldsworthy Engineering for the design of a machine capable of automatically placing fiberglass tape along any contour that could be anticipated for future composite components.

These efforts resulted in the numerically controlled Automated Tape Layup System (ATLAS). This

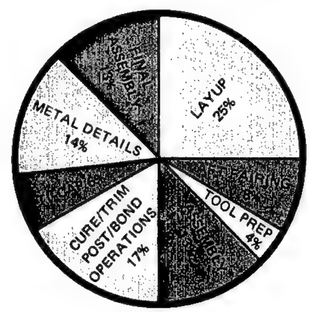


machine has six linear and curvilinear degrees of freedom in which it can operate simultaneously to produce irregular surfaces with several compound curves. The tape can be sheared automatically at termination, and also for "stepping back" succeeding layers to achieve the desired thinning near the trailing edge and tip of the blade. Near the inboard portion, the tape can be slit automatically into narrow ribbons to preclude tape deformation or wrinkling when it is blended into the root connection. The ATLAS also can keep the adjacent wraps of 2-inch tape within ± 0.010 inch of each other regardless of the contour being wrapped.

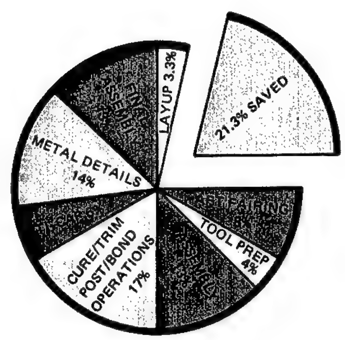
Dramatic Savings Seen

Not only are the components produced with the ATLAS of higher quality and reproducibility than is possible with hand layup, they also are produced in far less time. For example, work that formerly required 4000 hours for a 34 foot rotor blade can be accomplished in 250 hours using the ATLAS.

The ATLAS presently is installed at Boeing-Vertol and has served in the development of fiberglass components for CH-47 modernization, the Navy CH-46, and the UTTAS. In addition, the ATLAS is being used to establish and validate key parameters



HAND LAYUP



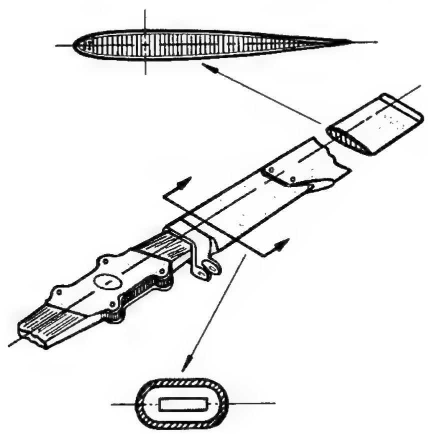
AUTOMATIC LAYUP

for the design of production oriented machines—parameters such as the required degrees of freedom, tooling requirements, consistency of layup, and cutter definition. These machines will allow the layup of from 30–100 pounds of material per hour in full scale production, compared with a hand layup rate of only 0.33 pound per hour. A further indication of the magnitude of the benefits derived by development of the automated layup capability is seen by comparing the man-hours required for hand layup of a composite rotor blade with those required using automated techniques.

New Techniques Soon in Use

Looking at other programs, Sikorsky is developing techniques un-

der an Air Mobility Research and Development Laboratory contract, to produce tail rotor assemblies that consist of unidirectional graphite-epoxy beams extending through the hub areas. The outer skins are cross ply composites which form the blade contours and take the torsional loads,



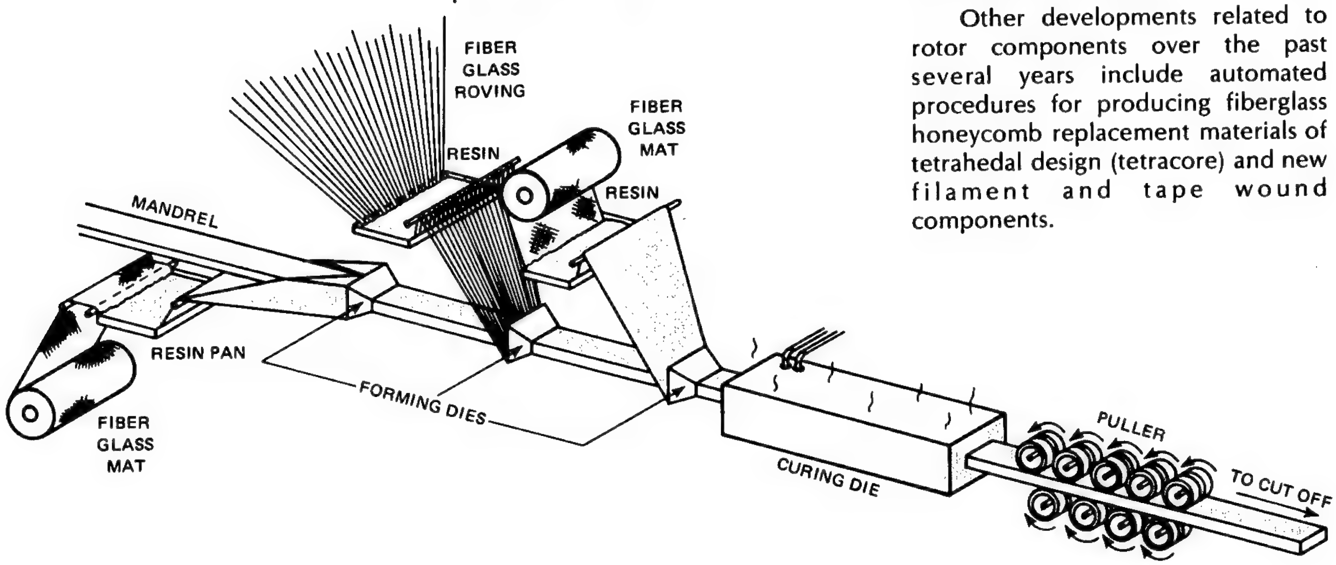
and the honeycomb cores are Nomex. The spars are flexible, allowing all the pitching and flapping that normally would require a number of bearings.

The pultrusion process is used to produce the cross beams under this program. This automated process, which can be used to produce a variety of composite structures, utilizes dry filaments that are pulled through an epoxy resin bath prior to their being formed to the desired shape in a die.

A portion of the graphite filaments in the construction under study extend from tip to tip; however, in the hub area the filaments must be spread around the cutout region while in either an uncured or "B" stage. Width and thickness doublers, which include ± 20° off angle plies, must be used for root-hub buildup to provide the load carrying capacity around the cutout area.

This automated technique for producing a one-piece flexbeam spar and hub assembly provides an economical tail rotor that eliminates components such as pitch and thrust bearings and also separate hub connections. Use of this rotor assembly in the Sikorsky UTTAS is anticipated; its utilization in other helicopters will produce cost, maintenance, and operational advantages over more conventional tail rotors.

Other developments related to rotor components over the past several years include automated procedures for producing fiberglass honeycomb replacement materials of tetrahedal design (tetracore) and new filament and tape wound components.



Parts II and III of this series will appear in future series of the **ManTech Journal**. Part II will describe drive system and turbine-engine manufacturing technology. Part III will project manufacturing improvements over the next years.

Less Energy Consumed

Technologies Lead to Conservation

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Energy crisis! Hardly news, but its very truth makes it worth constant repetition and reemphasis. America IS in the midst of an insidious energy crisis! Insidious because it is largely beneath the surface. A crisis in the literal sense because the situation has the very real potential for triggering ruinous, double digit inflation; shutting down industrial plants; reducing agricultural output; sharply increasing the number of unemployed; lowering living standards; and ultimately touching off economic blockades that could easily escalate into military actions.

DOD Responds to Challenge

The United States is faced with a clearly defined energy crisis and the DOD, one of the nation's largest energy users, is developing energy conservation programs in answer to the crisis. Within the DOD, Army Ammunition Plants (AAPs) are among the largest consumers of energy. As part of a $7 billion Munitions Production Base Modernization and Expansion Program launched in 1970, an energy technology project was initiated in late FY 75. This project is designed to investigate new energy technologies and to conduct pilot scale demonstrations. An initial energy inventory of six AAPs indicates a potential energy savings of 20 percent. This represents better than $6 million

on a combined annual energy budget of more than $29 million.

Some specific potentials for significant energy conservation include improved insulation, waste heat recovery, removal of high explosive fillers with a cavitating water jet, reduced forging temperatures, and energy recovery from solid wastes. The application of advanced technologies such as nuclear power, conversion of biomass, solar energy, and geothermal steam and water utilization is also an important part of the program.

Beyond pursuing specific technologies, each modernization project in the larger program is carefully reviewed for its energy implications before approval.

Public Attention Focused

The urgent need for effective energy conservation and management brings an intense national focus on energy resources, and the associated economics has created public and corporate attitudes which clearly establish goals such as:

- Increasing efficiency of energy use in factories, buildings, and transportation
- Curbing energy waste in energy production processes.

This clear concern within both the public and private sector has imparted new impetus to energy technology investigations relative to manufacturing technology. Still, there is evidence that even greater concern is needed.

President Nixon set 1980 as a target for national self sufficiency in energy needs when Project Independence was announced in 1973. However, architects of the Federal Energy Administration blueprint rejected this idea, opting instead for a goal of independence from "insecure" foreign oil by 1985 and emphasis on strict conservation measures to reduce the volume of energy imports.

Even this more modest current objective is now in serious jeopardy. In its 1976 report to Congress, the Energy Research and Development Administration noted a "widening" gap between demand and domestic production of oil. Robert C. Seamans, Jr., ERDA administrator, stated to Congress that it was "impossible to exaggerate the need to make more efficient use of energy."

It is against this grim backdrop that energy conservation programs have been developed by all substantial energy users within the Department of Defense, which accounts for a significant fraction of total national energy consumption.

Staggering Amounts of Fuel Consumed

One can easily visualize the huge amounts of liquid fuels required for mobility missions—to power airplanes, ships, and all types of land vehicles. Furthermore, it is equally easy to appreciate the large quantities of fossil fuels and electricity (usually produced from fossil fuels) needed to satisfy utility requirements for America's worldwide network of military camps, posts, and stations. But it is somewhat more difficult to comprehend the staggering quantities and diverse types of energy needed to operate the production plants which manufacture ammunition. Some of the AAPs, for example, are among the largest consumers of energy within the DOD. In fact, one large plant consumes enough energy to support a community of 15,000 residents. Table 1 shows the nine largest DOD thermal energy consumers and their annual consumption; the top three of the group are AAPs.

Energy Technology Applied

Because AAPs are large energy users and their products are essential to national defense, a comprehensive energy technology applications project (MM&T) was established in late FY 1975 to complement the energy conservation efforts already in effect at AAPs. Sponsored by the Project Manager for Munitions Production Base Modernization and Expansion, this energy technology project has a dual purpose, namely:

- Conserving rapidly dwindling fossil fuel resources
- Reducing the cost of munitions manufacturing and loading at AAPs by reducing associated energy consumption.

LARGEST DOD THERMAL ENERGY USERS

	Total Consumption, MBTU	Average Power, Megawatts
Holston Ammunition Plant, Tennessee	8,815,399	295
Radford Ammunition Plant, Virginia	6,830,511	230
Joliet Ammunition Plant, Illinois	3,538,842	120
Wright-Patterson AFB, Ohio	3,221,000	110
Fort Lewis, Washington	2,801,502	95
Philadelphia Naval Shipyard, Pennsylvania	2,788,126	95
Pearl Harbor Public Works, Hawaii	2,687,800	90
Fort Bragg, North Carolina	2,589,825	85
Redstone Arsenal, Alabama	2,576,607	85

TABLE 1

In 1970, a decision was made to overhaul the AAPs. At that time, the production base was comprised of 25 government owned, contractor operated (GOCO) plants and 5 arsenals, all embodying technology developed prior to or during World War II and the Korean War.

In this era of severe competition for resources, this outdated technology cannot be tolerated—it is absolutely essential that production of munitions be based on the latest state of the art. Modernization and expansion of these plants will cost in excess of $7 billion; this is needed to renovate and expand facilities and equipment having a replacement value of over $11 billion. Considering these costs and the fact that low cost energy is no longer obtainable, new economical energy technologies with specific applications to the munitions production base are being developed.

The modernization program which has been in effect for the past five years will continue through the 1990's. The program duration provides an opportunity to develop new energy technology applications and incorporate them into the production base. When a facility is being modernized in the near time frame, it must utilize existing or "off the shelf" technology. On the other hand, when a facility project is submitted for intermediate or long-term implementation, it is an appropriate vehicle for the incorporation of new site specific, process specific energy technologies.

Task Criteria Established

In order to utilize funds fully, the Project Manager set up the following criteria for task acceptance during the energy technology project: Each task must

- Be appropriate for manufacturing methods and technology effort (not R&D or off the shelf)
- Involve unique applications to munitions production
- Support modernization of the munitions production base
- Have a proposed AAP designated as a test bed or demonstration site
- Have a definitive timetable and a specific, achievable end product
- Be cost effective.

The omnibus energy technology applications project has some similarity to a multiyear, multitask pollution abatement project also supported by the Project Manager. Both are managed technically by Picatinny Arsenal, involve participation by Edgewood, Frankford, and Picatinny Arsenals, and are comprised of a series of tasks, each of which is in effect a miniproject. Specifically, the energy project includes investigation of new energy technologies and conduct of pilot scale demonstrations.

At an early stage in the project formulation, it became apparent that detailed energy consumption information on a unit process basis in the manufacturing plants was not available. Although the total energy generated and used could be clearly identified, there was no data on how that energy is used. Consequently, it was considered essential to get this kind of information as early as possible to insure the maximum benefit to be derived from energy conservation measures. This became the first step in the program.

Energy Consumption Inventory Taken

Prior to undertaking detailed energy audits at the various plants, a preliminary study was made at six Army

Ammunition Plants covering the spectrum of Propellants and Explosives (P&E), Metal Parts (MPTS), and Load, Assemble, and Pack (LAP). These audits identified and evaluated the energy savings potential at various types of plants. Essentially, this study addressed the generation and transmission of energy at the individual plants, and, to a more limited extent, it examined the energy usage during processing operations. The results (Table 2) indicated a savings potential of 20 percent, with approximately 8 percent attainable by procedural improvements and the remaining 12 percent requiring capital investment. Payback periods of one to three years were the general rule in cases where capital investments were required. Thus, without a complete and detailed energy inventory, numerous significant opportunities for energy conservation are apparent.

In order to establish adequate baselines, however, on the amount of energy actually consumed during manufacturing operations at the various AAPs, detailed process energy audits are being vigorously pursued as part of the energy conservation technology project. These audits are conducted in a stepwise fashion for those operations and processes that are known to be energy intensive. From the energy audit data, energy intensive operations and processes will be identified and designated for various energy conservation techniques.

A first step is the acquisition of instrumentation to measure usage of energy that is primarily in the form of steam and electricity. The data obtained will be compared with theoretical data on energy requirements. Where there are large discrepancies in energy required vs energy utilized, actions will be taken to improve the efficiency of energy utilization, with the overall objective of reducing the energy expenditure per unit of product manufactured. These actions may be simple modifications in operating procedure or they may be full scale engineering technology projects required to accomplish the desired improvement.

ENERGY USE AND IDENTIFIED SAVINGS POTENTIAL AT SIX ARMY AMMUNITION PLANTS

Army Ammunition Plant	Type of Plant	Annual Energy, $	Non-Capital, $	Savings Potential Capital, $	Total, $	% of Annual Energy
Radford	P&E	11,200,000	998,500	985,900	1,984,000	17.7
Holston	P&E	7,920,000	630,400	1,340,500	1,970,900	24.9
Iowa	LAP	3,060,000	112,000	732,300	844,300	27.6
Scranton	MPTS	3,000,000	196,100	294,400	490,500	16.4
Volunteer	P&E	2,200,000	259,400	222,200	481,600	21.9
Lake City	MPTS	2,000,000	119,000	142,800	261,800	13.1
Totals		29,380,000	2,315,400	3,718,100	6,033,500	20.5

Non Capital Savings	$2,315,400/Yr	= 38.4%
Capital Savings	$3,718,100/Yr	= 61.6%
Total Savings Potential	$6,033,500/Yr	= 100.0%

TABLE 2

Infrared Thermography "Sees" Loss

Among the newer technologies to be utilized in the energy inventory is infrared thermography. This technique relies on the fact that all objects radiate energy at a finite temperature, this energy being primarily in the infrared region at near ambient temperatures. Thus, it is possible to capture a temperature profile or thermogram of a given object by the use of an infrared camera that is capable of detecting, measuring, and harnessing this radiant energy. This is precisely what infrared thermography does (Figure 1); the technology has found widespread application in recent years in such fields as space science, defense systems, and medicine. It now appears to offer great promise in energy conservation.

By obtaining the temperature distribution of an object, it is possible to rapidly detect regions of high temperature which represent heat losses. In fact, not only is it feasible to discern qualitatively where heat is being rejected, but it is also possible to obtain quantitative information on heat losses. During the energy use audit, infrared thermography will be used to isolate those process operations where there are large heat losses and to determine the amount of heat loss involved.

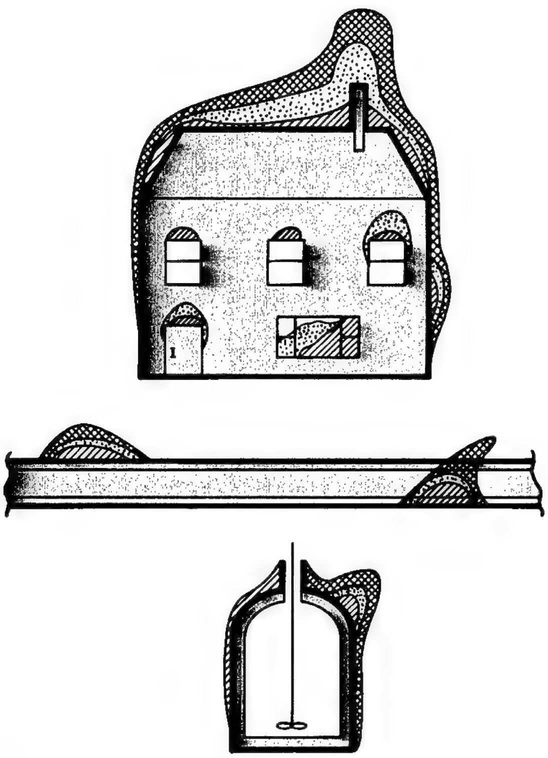

FIGURE 1

Insulation Needed

The use of advanced insulation technology in process equipment offers a real opportunity to conserve energy. Traditionally, equipment used to process explosive type materials has been devoid of insulation because of the potential problem of incompatibility of the explosives with the insulating material. This philosophy is now being reexamined because of the large potential for energy conservation and the availability of improved insulating materials.

The types of savings that can be achieved through insulation are illustrated in Table 3, which cover the purification of nitrocellulose. During this process, large quantities of dilute nitrocellulose water slurries—as much as 20,000 gallons per vessel—are maintained a a temperature of 205 F for as long as three to four days. The vessels (which are constructed of either wood or stainless steel) have no insulation. They therefore represent an excellent opportunity to conserve energy through insulation.

INSULATION OF NITROCELLULOSE BOILING TUBS

- Application: Purification of Nitrocellulose
- Item: Boiling Tubs
- Temperature: 205 F
- Potential Energy Savings: ~1140 x 10^6 Btu/Year (Per Tub)
- Capital Investment: ~$390,000 (90 Tubs)
- Yearly Savings: ~$250,000 (90 Tubs)
- Payback Period: ~1.6 Years
- Yearly Equivalent: ~1000 $\bar{M}$ SCF Gas or 730,000 Gal Oil

TABLE 3

Heat Pipe Recovers Waste Heat

Energy recovery from waste heat presents virtually unlimited opportunities for energy conservation particularly in propellant and explosives plants. Since most of the chemical reactions that take place are exothermic, enormous amounts of heat are liberated. At the same time, it is invariably necessary to rapidly remove the liberated heat in order to maintain the reaction temperature at the prescribed level and thereby prevent a "runaway" reaction. This is commonly accomplished with cooling water, resulting in a waste of energy. Similarly, there are numerous other examples of unit operations that take place at elevated temperatures where the heat involved is dissipated to the atmosphere in a wasteful manner. Potential applications for the recovery of waste heat are being closely examined to determine which ones are most likely candidates.

One of the newer technologies that is being considered as a strong candidate utilizes the heat pipe (Figure 2). This unique heat exchange device is a self contained, closed system with no moving parts, which requires no external power sources. It utilizes the principles of heat absorption via liquid vaporization and heat rejection via liquid condensation. Heat pipes are especially attractive for potential use in propellant and explosives plants because of their high efficiency, separation of inlet and exhaust streams (which prevents cross stream infiltration and contamination), and ease of maintenance and cleaning of heat transfer surfaces. Table 4 summarizes the benefits to be derived from a possible heat pipe application in the forced air drying of a multibase propellant. The potential for saving both dollars and fuel is clearly evident.

HEAT PIPE TECHNOLOGY FLOW PATTERNS IN A HEAT PIPE

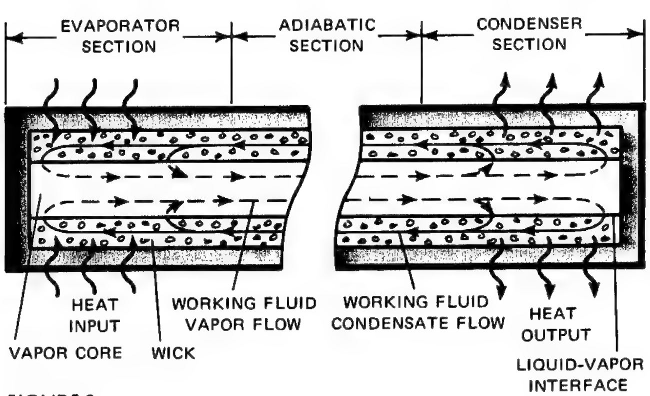

FIGURE 2

Cavitating Jet Cuts Loss

A new technology area that has been identified as an energy conservation measure in the load, assemble, and pack plants involves the use of a cavitating water jet to remove high explosive fillers from loaded projectiles. The conventional procedure for down loading projectiles is to melt out the explosive fill using steam. This is an energy intensive operation. The proposed method is based on the application of a cavitating force to erode away the explosive material (Figure 3). This is a powerful, essentially mechanical force, which can be induced locally on the sur-

RECOVERY OF HEAT FROM PROPELLANT FORCED AIR DRYING

- Application: Drying of Multi-Base Propellant
- Air Flow: 5500 CFM (Per Bay)
- Air Temperature: 140 F
- Potential Heat Recovery: ~2550 X 10^6 Btu/Year (Per Bay)
- Capital Investment: ~$15,000 (Per Bay)
- Yearly Savings: ~$8,000 (Per Bay)
- Payback Period: ~1.9 Years
- Yearly Savings: ~$780,000 (96 Bays)
- Yearly Equivalent: ~245 $\overline{M}$ SCF Gas or 1.7 $\overline{M}$ Gal Oil

TABLE 4

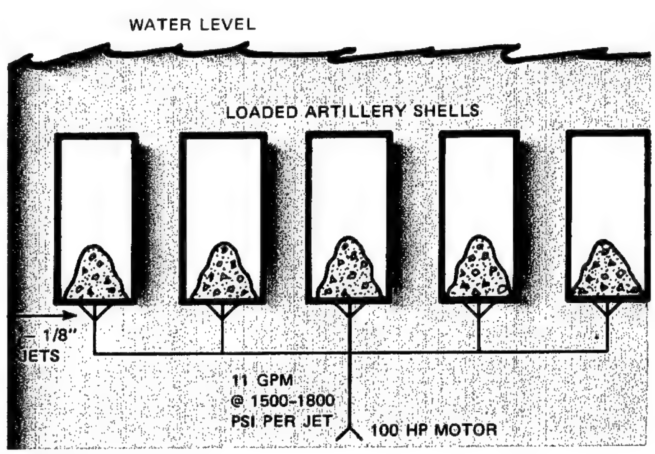

FIGURE 3

face of the material acted upon by the collapse or implosion of vapor bubbles in a liquid medium. The replacement of the hot water washout operation by cavitational removal of rejected 105-mm explosive loads is expected to reduce energy requirements by a large factor (Table 5).

WASHOUT VS CAVITATION		
LSAAP, 105MM OPERATION		
	WASHOUT	CAVITATION
Energy Requirement, Btu/Hr/Line	∼4.7M̄	∼170,000
Steam – Equivalent, Lb/Hr/Line	∼4700	∼170
Yearly Cost, $/Line	∼$90,000	∼4000
Yearly Savings, $/Line	∼$86,000	
Yearly Equivalent: ∼24M̄ SCF Gas or 200,000 Gal Oil		

TABLE 5

Reduced Forging Temperatures Possible

The metal parts manufacturing plants also offer significant opportunities for energy conservation by introducing new technology. One typical example is the reduction in the forging temperatures that are used in the fabrication of metal projectile parts. Laboratory studies indicate that forging temperatures can be reduced from their current level of 2200 F to 1900 F without interfering with the capacity of the plants to produce the required tonnage. The fuel and cost savings that would result from this technology improvement are shown in Table 6.

Energy Recovered From Solid Waste

Not only is energy conservation technology being used to reduce consumption of domestic fossil fuels that are in short supply, but in addition, alternate forms of energy are being considered to relieve the burden on these critical fuels. One untapped source of energy is the large amount of solid waste that is generated in the Army ammunition plants, particularly those that manufacture propellants and explosives. Studies are in progress to determine the optimum methods of energy recovery as well as various pyrolysis processes (Figure 4) to convert the refuse into usable forms of fuel.

In pyrolysis, the organic portion of the waste is broken down at elevated temperatures in the absence of air to produce synthetic fuel gas and/or oil. One unique feature of munitions plant refuse is that it is comprised of both explosive contaminated material and pure explosives; the potential hazard restricts the choice of energy recovery methods. Current plans call for investigating pyrolysis technology to produce storable synthetic fuels from munitions plant solid waste. One economic analysis of a pyrolysis process that yields synthetic fuel oil as its primary product is given in Table 7. This analysis takes into account the elimination of incineration as a currently approved method for disposal of explosive waste in order to meet pollution abatement standards. On this basis, the capital cost of a 50 ton per day pyrolysis unit can be amortized in less than six years.

REDUCED FORGING TEMPERATURES		
SCRANTON AAP 155MM M107		
	CURRENT	PROPOSED
Mult Weight, Lb	120	120
Production Rate, Proj/Mo	50,000	50,000
Forging Temperature, °F	2200	1900
Energy Requirements, Btu/Mo	∼3000 x 10^6	∼2735 x 10^6
Yearly Savings:	∼$6000	
Yearly Equivalent: ∼2.6M̄ SCF Gas or 22,000 Gal Oil		

TABLE 6

ECONOMIC ANALYSIS OF PYROLYSIS

• Plant Capacity:	50 TPD
• Capital Investment:	$1,200,000
• Operating Cost:	$12,31/Ton
• Refuse Energy:	6,000 Btu/Lb
• Product From 1 Ton:	56 Gal Oil at 114,000 Btu/Gal
• Value of Oil:	$2.50/M Btu ($0.35/Gal)
• Energy Credit:	$16.00/Ton
• Operating Profit:	$3.69/Ton
• Current Disposal Cost:	$8.80/Ton
• Net Profit:	$12.49/Ton
• Annual Net Profit:	$206,000
• Payback Period:	5.8 Years

TABLE 7

Advanced Technologies Trigger Innovation

The energy technology project has already stimulated a considerable amount of innovative thinking regarding applications of advanced technologies. Radford Army Ammunition Plant is being considered as a possible site for a 100 MW nuclear reactor to supply both the thermal and electrical requirements of this large P&E facility. One installation has made a proposal to convert biomass (which it will grow locally) into a usable fuel by bacterial action or alternatively to burn the biomass for its caloric content. Solar energy schemes have been proposed to use this nonpolluting energy source for space heating and cooling, and to supply heat for unit processes or operations—e.g.,drying of propellants and explosives. One proposal seeks to explore and tap geothermal steam and water contained in strata underlying an installation designated as a site for a new facility.

In order to be incorporated into this project, proposed tasks must meet the above mentioned task acceptance criteria and must survive a critical review of their priorities, at which available funds are assigned to tasks having the greatest potential for widespread use and early payback.

All Engineers Trained

All engineers within the Project Manager's office have been given energy training and shown appropriate films to enhance their awareness in the energy area and to make certain that the energy implications of each modernization project are fully explored, alternatives considered, and a position taken which is consistent with national and DOD energy objectives.

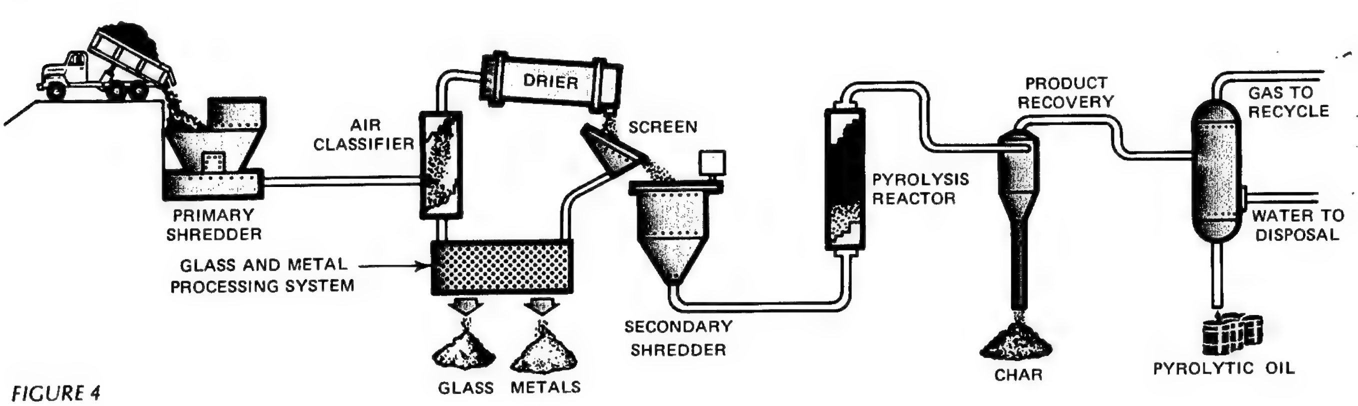

FIGURE 4

US Army

ManTech Journal

A Partnership With Industry

Volume 2 / Number 2 / 1977

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US Army
ManTech Journal

Contents

ABOUT THE COVER:

The marriage of turret and hull of this M60A1 tank is seen in this photograph taken during a production run at the U.S. Army's Detroit Arsenal Tank Plant. This final step in the production process represents the consummation and implementation of many new manufacturing technologies developed by the Tank Automotive Research and Development Command for use in Army armored vehicles. Some of these manufacturing techniques are described in detail in the Highlights section of this issue of the *Army ManTech Journal*.

Comments by the Editor

DR. JOHN J. BURKE

A look at current news items in other manufacturing publications reveals the fact that private industry and the Army are moving along similar paths toward greater efficiencies and less costly production. For example, we see the large automobile companies looking hard at production applications for computer control of their manufacturing operations, not only in the fabrication of parts but also in the monitoring of inventories and pieces in process. Better planning, smoother utilization of materials and manpower, and a more comprehensive perspective of overall operations result.

And we see the investment casting industry committing heavily to robots for the production of heavy shells in severe environments; meanwhile, the die casting industry is investing in closed loop programmable electronic controllers for its operational processes. Their efforts will be rewarded, respectively, by more uniform products and greater safety, and the saving of vast amounts of energy through use of precise process temperatures.

The list of articles in this issue of the Army ManTech Journal reads like a sequel to the news items just mentioned. Featured are articles on the Tank Automotive Research and Development Command's efforts in automated gas welding, polyurethane castings, computer aided design and machining of forgings, development of powder metal gears, and aluminum faced treads. Not to mention the automation and sophisticated measuring techniques detailed in the articles by other Army personnel and one civilian firm. We see, also, from our news item scan that automated measuring and monitoring is in store for the rotary forge operation at Watervliet Arsenal, which is discussed in another article in this issue.

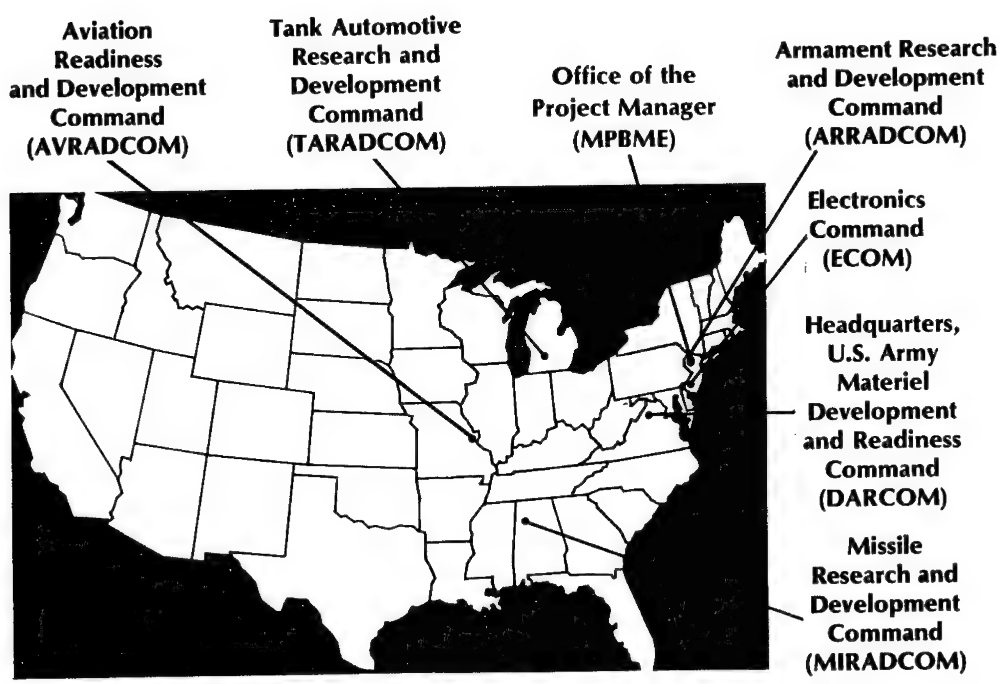
Perhaps the major difference between the events occurring in manufacturing technology in private industry and in the military is the full spectrum aspect of the military program and its integrated, coordinated nature. Few private industries have so wide a base of operations as does the military, hence private industry's programs tend to be more specialized. We hope our wide ranging efforts are put to early use in the private sector of our economy, enabling commercial firms to profit from our developments.

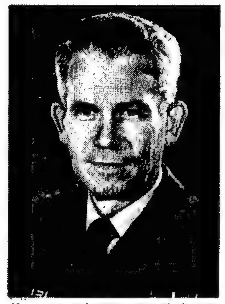
Cancellation of the B-1 bomber program leaves one fact that is certain — any large manufacturing challenge such as typified by that program produces many side benefits which industry and the economy will enjoy. For instance, the sophisticated techniques of machining and bonding developed during the B-1 program will be put to use in many other applications, both military and civilian. And the composites planned for use in the tail section of the aircraft will produce a whole new level of performance, reliability, and lowered fabrication cost in helicopters, as detailed in the articles appearing in the past,

current, and next issues of the ManTech Journal. Whether these techniques were directly the result of any one program is beside the point — new technical developments, once achieved, exist long after the program in which they were developed stops. And the developments from so large and complex a program as that for the B-1 can be numbered in the hundreds, with all of them now available for other military application or new commercial uses.

One last note of interest turned up in our scan of current news items — consideration by the Department of Defense of special tax credits to contractors who have invested in new cost saving equipment for a military contract and have had the contract stop prematurely. This type of support has been discussed in several articles carried in past issues of the ManTech Journal, and all authors concur that such relief can bring only good to the arena of military contracting, where a progressive firm anxious to develop new methods of production sometimes suffers heavy capital loss after investing heavily in new equipment or processes. The implementation of such an investment tax program by the Department of Defense will have a dramatic effect on manufacturing technology developments by military contractors in the future.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods





MAJOR GENERAL OSCAR C. DECKER, JR., assumed command on 1 July 1976 of the U.S. Army Tank Automotive Research and Development Command, Warren, Michigan. General Decker previously had served as Deputy Commander and as Director of Procurement and Production at the U.S. Army Tank Automotive Command. A native Nebraskan, he began his Army service in 1943 as an enlisted man in Armor. When he was discharged in 1946, he returned to the University of Nebraska, where he graduated in 1951 with a degree in Business Administration. After commissioning in the Ordnance Corps he was detailed to the Armor Branch, where he served with the 2nd Armored Division in Europe. Following this tour of duty, he attended the Ordnance Advanced Course and the Command and General Staff Course. He later received a Master's Degree in International Affairs from George Washington University. General Decker has served as a Battalion Commander both in Europe and Vietnam; as Project Manager, Armored Reconnaissance Scout Vehicle; and as Executive Assistant to the Assistant Secretary of the Army (Installations and Logistics).

Techniques Of Value To Industry

Logistics Demand: Quick Returns

Shorter lead times and lower costs—these are the two critical production objectives on which the Tank Automotive Research and Development Command has focused its manufacturing technology program. After the desperate need arose for armored vehicles to replace heavy losses during the 1973 Mid-East conflict, the Army was charged with improving its ability to satisfy future heavy demand for tank production on short notice. At the same time, budgeting constraints have made money tight for accomplishing this end. TARADCOM is meeting the challenge head-on with a program that seeks to establish and implement the latest, most advanced techniques and processes for producing armored vehicles. Production of these combat vehicles is a dynamic activity in which manufacturers must cope with rapidly changing technologies, long lead times, short normal production runs, and large capital requirements—all of which combine to work against fulfillment of the logistic demands placed upon the industry.

Automation Cuts Lead Time

Long lead times probably are the most severe handicap to increasing the production rate, becoming a critical problem when demand rises sharply. The problem is most acute in labor intensive areas—e.g., the casting industry. To overcome this handicap, TARADCOM is directing efforts toward automated fabrication processes and computer controls to improve both the quality and productivity of its processes; casting is a prime example. Initially, these efforts are being aimed toward small components such as track shoes, road wheels, engine cylinders, crankshafts, sprockets, starters, regulators, generators, and batteries. As the technology develops and improves thru this application to small parts, it will be expanded to include larger components, all the way to the hull and turret.

Industry A Partner

The second major thrust of TARADCOM's Manufacturing Methods and Technology effort is reduction of costs. The program is especially important should demand increase

when severe budgetary constraints are in effect. In October, 1976, TARADCOM conducted a Vehicle Manufacturing Technology Conference to make its manufacturing technology program more responsive to this goal. At the conference, industry spokesmen presented proposals to improve manufacturing processes and reduce costs. This followed a preconference effort—in cooperation with industry—to identify manufacturing shortcomings and cost drivers.

Planning Shrinks Costs

The conference and its planning initiated a major effort to include industry in the planning stages of the manufacturing process. By doing this, TARADCOM is encouraging introduction of newly developed processes at earlier dates, with subsequent reductions in costs. This conference was most productive; the manufacturing technology program for the next five years was charted largely from conference inputs. Utilization of industry input will make sure that program funds are spent on realistic projects. For example, the identification of cost drivers is of paramount importance; several vehicle and component manufacturers have provided data that clearly reflects high cost areas—opportunities for cost reduction.

The implementation of the conference recommendations has led to the initiation of projects to utilize advanced technologies to manufacture tank turbine engine components. Examples include an effort to apply laser welding technology to join the interior plates of an advanced design turbine engine recuperator. Another effort deals with developing a low cost manufacturing process for fabricating compressor wheels for the turbine engine. Work also will be conducted to upscale the powder metal forging process to large tank parts.

Particular parts and also major technology areas representing significant potential cost savings were identified. For example, in three combat vehicle systems—the XM1 Tank, M60A1 Tank, and Infantry Fighting Vehicle—seventy-nine parts have been identified that represent a planned average discounted anticipated investment of more than $4.9 million per part through the period considered. Of these, fifty-one have both a significant material cost and a significant fabrication cost, a fact which makes them prime targets for attack in the manufacturing cost reduction program.

High Potentials Selected

Materials and processes that represent high investment areas have also been identified. The data developed highlights the major cost areas and also the associated technologies that offer the best potential for manufacturing technology investment. To develop this potential, a wide variety of manufacturing technology programs are being conducted. The reader will find a few detailed reviews of them in featured articles elsewhere in this issue. There are many more, however, than these that are highlighted.

For example, in the area of computer aided manufacturing, in addition to the forging and automated hull welding programs covered in featured articles, TARADCOM is also developing automated electron beam welding and casting. The automation of electron beam welding will be applied to the joining of aluminum armored vehicles. An important feature of the electron beam process is its high penetration, which allows thick aluminum armor to be welded in a single pass. In addition, the electron beam heat affected zone is so very small that ballistic properties of the armor are improved. At present, electron beam welding must be done in a vacuum chamber. Technology advances, however, indicate that in the near future both electron beam and laser welding of combat vehicles will be possible without vacuum. With these improvements, either of the processes—or a combination of them—could result in the most economical, efficient, and ballistically acceptable weld joint available.

Computers Brought to Bear

A computer aided manufacturing project on casting has been initiated to develop use of the computer to apply advanced fluid flow and thermal analysis to casting operations. This would result in more efficient use of casting facilities. Present casting processes are highly inefficient in usage of raw materials and energy. For example, a typical cast configuration contains only about two thirds of the starting raw material. To develop the new technology, an interactive computer design system will be used that

simulates the casting process, which will allow consideration of more alternate locations and sizes of gates and risers. By anticipating casting defects, preventive measures can be taken in designing the molds and patterns.

Ballistics/Weight Trade-off

In another program, the forging of cast armor preforms has been investigated. This process promises to produce large armor components with better ballistic protection or with equal protection and reduced weight. It combines the advantages of casting and forging in a two-step operation. A hull section is first cast into the approximate finished shape and is then forged to finished dimension on a hydraulic press. A 10,000 lb hull front would be 800 pounds lighter than a similar cast item and would offer equal ballistic protection. The process is applicable to any large armor subcomponent contemplated in future vehicles.

Other New Processes Pay Off

Powder metallurgy techniques are being considered for fabrication of pistons, as well as the gears discussed in a featured article in this issue. Present aluminum brake cylinders promote galvanic corrosion in contact with the gray iron cylinder housing. To overcome this problem, sintered iron pistons were made from iron powder with a small quantity of babbit. Density of the material was controlled to about 2 percent porosity and the pores were impregnated with synthetic preservative lubricant. When tested on trucks for 10,000 miles and subjected to saltwater environment tests, the sintered iron pistons showed neither undue wear nor corrosion. In the same tests, aluminum pistons were corroded and gummed.

The use of dissimilar metals in vehicle fabrication is attractive from a weight saving viewpoint and allows the designer to take advantage of the most desirable properties of different materials. However, it introduces problems in joining. TARADCOM has recognized the advantage of using dissimilar metals for vehicle construction and has conducted tests on the joining of such dissimilar combinations as aluminum to steel and titanium to steel. The command has developed satisfactory techniques of fabrication and has demonstrated the feasibility of using such combinations of metals in welds.

Welding Procedures Critical

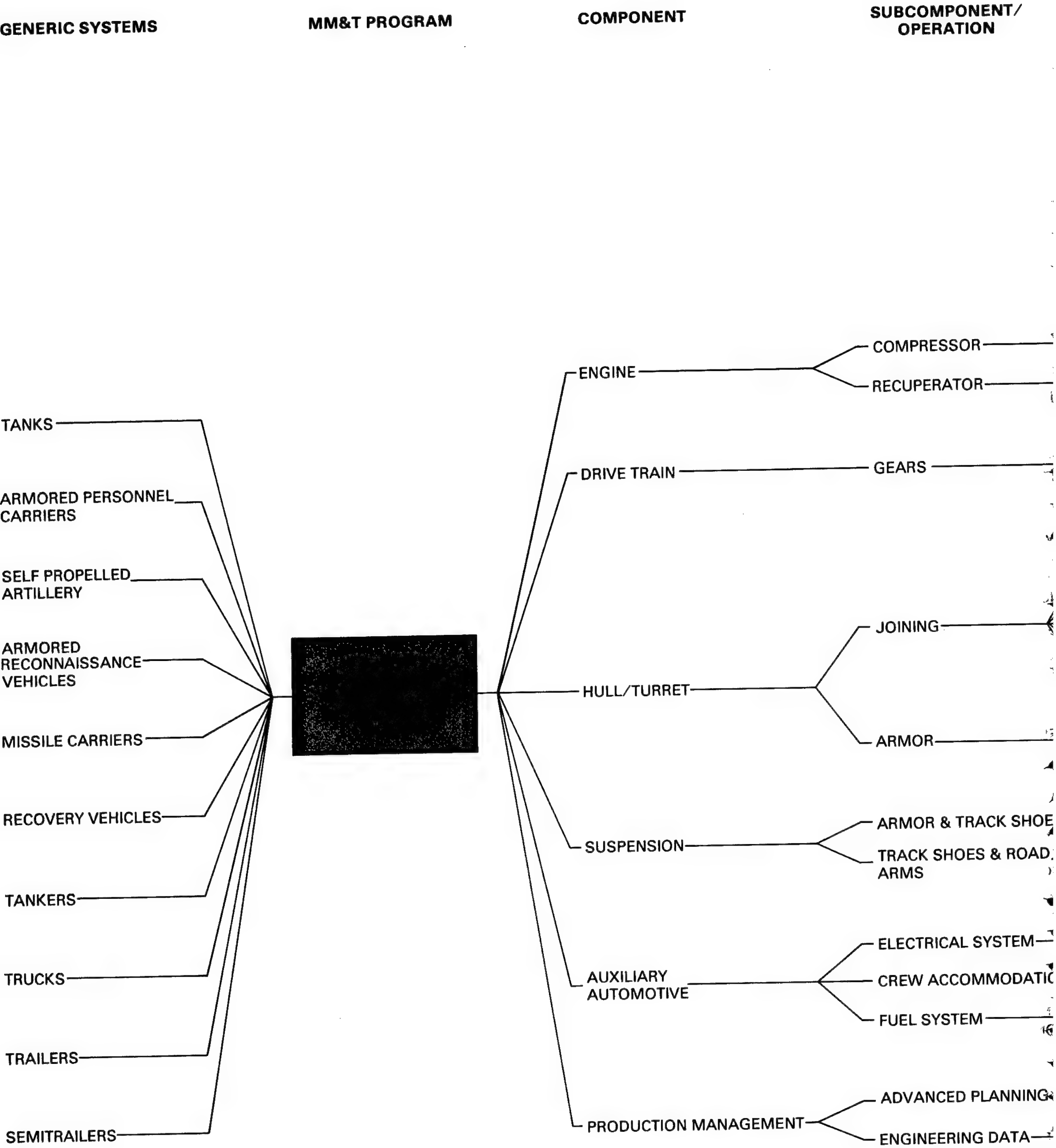
An investigation on welding of electroslag refined steel (ESR) is being conducted. Armor from this material can provide weight savings and/or improvements in ballistic protection up to 20 percent. The material has very high hardness and very low impurity, but its high carbon content makes welding very difficult. The objectives of the current program are to explore weld variables and develop processes that will ensure reliable welding on a production basis. The application of ESR armor to combat vehicles hinges on successful completion of this program.

In another welding program, TARADCOM successfully fabricated a pilot hull to determine the feasibility of using dual hardness armor in large structures. Vibration and stress induced by a shaker test revealed no weld joint weakness. The program confirmed that dual hardness steel is acceptable structurally for armor hull combat vehicles.

In yet another process needing improved technique, extensive machining operations are required to fabricate tubes for tube over torsion bar suspension springs. Fabrication techniques have been developed to decrease machining by either inertia welding the spline ends or upsetting them at the time the bar spring is being fabricated. With either method, substantial cost reductions will be realized.

Thrift, Productivity the Goal

TARADCOM will continue to provide total manufacturing engineering support to the Army's programs that procure military ground vehicle equipment. In so doing, repeated emphasis will be placed on cost reduction and the conservation of material, energy, and personnel resources. Full implementation of the technologies evolving from current and future programs will bring a new standard of productivity and thrift to our military equipment production base.



SPIDERCHART

MM&T PROGRAM: US ARMY TANK AUTOMOTI

ROJECT — **MM&T GOALS**

ROJECT	Reduce Manufacturing Unit Cost	Reduce Facility/Capital Investment	Reduce Production Base Response Time	Required for TDP	Improved Reliability	Improved Producibility	Facilitate Quantity Production	Solve Production Obstacle	Reduce Life Cycle Costs	Improved Maintainability	Improved Survivability	Improved Performance
GRALLY CAST LOW COST COMPRESSOR	•			•	•	•	•			•		
UCTION TECHNIQUES FOR FABRICATION URBINE ENGINE RECUPERATOR	•			•		•	•	•				
ALING OF ADVANCED POWDERED LLURGY PROCESSES	•			•	•		•		•			
MATED GAS METAL ARC WELDING OF ALUMINUM STRUCTURES IN MORE THAN ONE AXIS (CAM)	•				•		•					
UCTION METHOD FOR HIGH EFFICIENCY NG OF ESR ARMOR	•			•	•	•					•	
NG OF DISSIMILAR METALS						•			•		•	
ICATION OF ARMORED VEHICLES G ELECTRON BEAM WELDING	•		•		•	•	•				•	
NG OF STEEL ARMOR INTERMIX						•			•		•	
ESSING ESR STEELS FOR IMPROVED OGENEOUS ARMOR					•	•			•		•	•
OVED FOUNDRY CASTING PROCESSES	•		•		•	•						
ERMAL HEAT TREATMENT FOR HIGH IGTH DUCTILE IRON CASTINGS	•					•	•		•			
AGE BATTERY, LOW MAINTENANCE					•				•	•		•
OVED SEATING FOR MILITARY VEHICLES						•			•			•
ING OF LARGE CAPACITY FUEL TANKS OMBAT VEHICLES	•			•	•	•			•	•		
SATION		•						•	•			
ENGINEERING HANDBOOKS	•				•	•						•

TECHNOLOGY AREA

ROJECT	Materials Handling	Process Instrumentation	CAD/CAM	Automated Manufacture	Net Shape	Electronics Fabrication	Testing	Materials Processing	Metal Removal	Composite Fabrication	Logistics
GRALLY CAST LOW COST COMPRESSOR					•			•			
UCTION TECHNIQUES FOR FABRICATION URBINE ENGINE RECUPERATOR				•				•			
ALING OF ADVANCED POWDERED LLURGY PROCESSES					•			•			
MATED GAS METAL ARC WELDING OF ALUMINUM STRUCTURES IN MORE THAN ONE AXIS (CAM)			•	•				•			
UCTION METHOD FOR HIGH EFFICIENCY NG OF ESR ARMOR								•			
NG OF DISSIMILAR METALS								•			
ICATION OF ARMORED VEHICLES G ELECTRON BEAM WELDING			•	•				•			
NG OF STEEL ARMOR INTERMIX								•			
ESSING ESR STEELS FOR IMPROVED OGENEOUS ARMOR								•			
OVED FOUNDRY CASTING PROCESSES			•		•			•			
ERMAL HEAT TREATMENT FOR HIGH IGTH DUCTILE IRON CASTINGS					•			•			
AGE BATTERY, LOW MAINTENANCE						•					
OVED SEATING FOR MILITARY VEHICLES					•			•			
ING OF LARGE CAPACITY FUEL TANKS OMBAT VEHICLES					•			•			
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ENGINEERING HANDBOOKS	•				•	•	•	•	•	•	•

SEARCH AND DEVELOPMENT COMMAND

New Technologies Will Meet Challenge

Highlights of Major Achievements

The following articles on automatic gas welding, cast polyurethane track shoes, powder metal gears, aluminum vehicle tracks, and computer aids to design and machining of shoe forgings detail some of the achievements resulting from research by the Tank Automotive Research and Development Command. These achievements are forerunners of new technologies being developed that will enable TARADCOM to meet its challenge of providing shorter lead times in production and also reduced costs, meanwhile supplying the U.S. Army with the most advanced armored military equipment in the world. These highlight articles are followed by Brief Status Reports on manufacturing technology projects in progress.

Hull Joining Time Cut In Half

Automatic Welding of Steel Armor

EUGENE BALLA is a senior welding project engineer in the Armor and Components Division of the Army Tank Automotive Research and Development Command. He has been with the Command for seven years, initially participating in the Intern Career Training Program up to his present status. During this period he has served as both a metallurgical and welding engineer. He holds a Bachelor of Science Degree in Metallurgical Engineering and is a member of the American Society for Metals and the American Welding Society. Recently, he presented a paper in conjunction with Battelle Memorial Institute at the American Welding Society Convention concerning the automation of the Gas Metal Arc Welding Processes.

With more than a mile of welded joints, the modern tank hull structure is a prime candidate for automated welding processes. Recognizing this, engineers at TARADCOM developed a prototype computerized gas metal arc (GMA) welding machine that can cut the welding time on a steel hull in half. In addition, the machine automatically positions large parts for welding, providing further substantial savings over the present time consuming manual positioning operations. The automated process also insures quality with less reliance on human factors.

The prototype machine is presently installed in TARADCOM's welding laboratory. Engineers there are using this subscale system to develop welding parameter controls and program configurations necessary to weld hull armor. At present, TARADCOM is welding test plates designed to simulate the conditions of restraint found within welded vehicle structures. When fabricated, the plates will be tested for ballistic integrity at Aberdeen Proving Grounds.

During the next year, TARADCOM will develop controls to extend the automatic capability to aluminum hulls. This will require only slight modifications to the original automated equipment.

Ultimate integration of the equipment into the tank manufacturing process depends on the success of ballistic tests, further TARADCOM development, and manufacturer acceptance. The use of some automated process, however, is an obvious answer to impending soaring costs of welded hull fabrication.

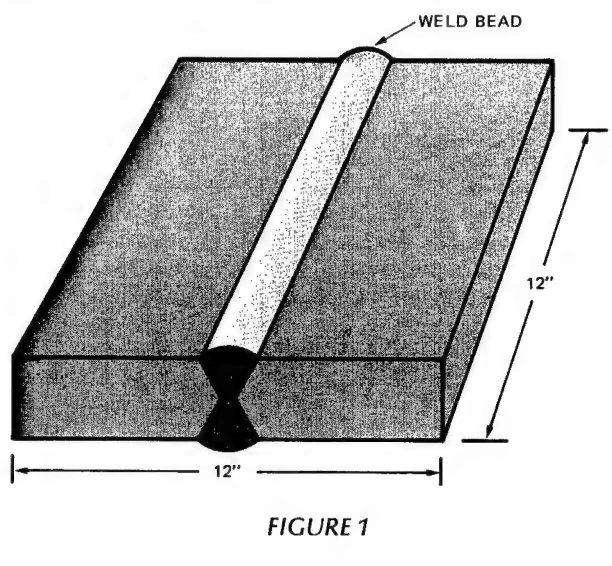


FIGURE 1

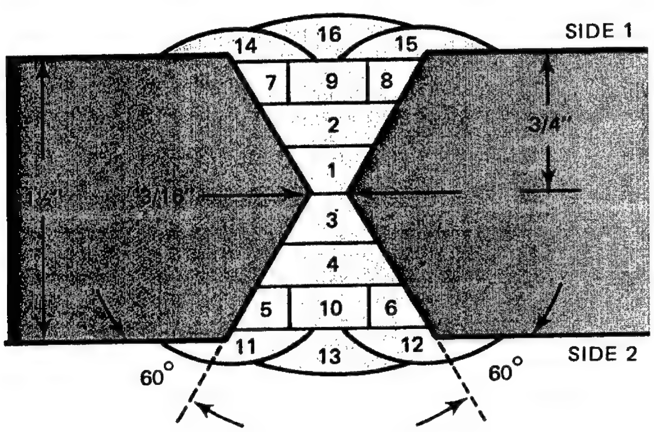
Weld Parameters Developed

An important part of the development effort is determining optimum welding parameters, such as amperage, voltage, and travel speed. TARADCOM is developing welding parameters for specific joint geometry utilizing small steel armor test plates (Figure 1). Figure 2 shows one configuration, a double vee groove joint. Parameters for a 16-pass weld, as developed from test plates, are shown in the Figure and in Table 1.

In making initial parameter development welds, only the manual numerical control mode of operation is used.

FIGURE 2

LOCATION AND SEQUENCE OF WELDING PASSES



Welding Power Supply Slope Characteristics	Flat
Welding Power Supply Slope Setting	00.0
Welding Voltage	27.0 volts
Welding Power Supply Weld Setting	55.0%
Welding Wire Diameter	1/16 in.
Wire Feed Speed	200 in./min
Wire Feed Speed Control Setting	1.93
Gas Type	97 Ar–30
Gas Flow Rate	50 cfh
Contact Tip Recess	0.125
Welding Current	330 amps, DCRP
Root Opening	3/16 in.

This ensures good weld quality prior to programming the computer numerical controls to produce completely automated welds. Metallurgical, mechanical, and nondestructive tests are run on all parameter development welds to ensure final quality.

Complex Designs Increase Costs

In the past, tank hulls were fabricated from a few large section castings. However, design trends to improve armor protection indicate that tanks will rely more and more on hull structures made from many smaller sections of wrought armor plate. Armor plate shapes will become more complex requiring more welds of greater length. These welds will require more time, more precise fixturing, and improved weld parameter controls, all of which serve to increase costs. Recognizing that automatic welding is one way to battle these costs, TARADCOM launched a program to design, fabricate, and evaluate an automated GMA system with five axes of control for welding armor plate.

TABLE 1

DETAILS OF JOINT WELDING PROCEDURE

Pass No.	Plate Side	Torch Centerline Offset, in.	Torch to Plate Distance, in.(1)	Travel Speed, in./min.
1	1	0	.050	6
2	1	0	.350	8
3	2	0	.100	7
4	2	0	.235	7
5	2	.250	.425	9
6	2	.250	.425	9
7	1	.250	.400	9
8	1	.250	.400	9
9	1	0	.500	7
10	2	0	.525	7
11	2	.425	.600	14
12	2	.425	.600	14
13	2	0	.600	12
14	1	.425	.600	14
15	1	.425	.600	14
16	1	0	.600	12

(1) Measured from bottom of nozzle to the plate surface.

Their prototype system, assembled from commercially available equipment, consists of:

- A probe, operating on the eddy current principle, to track the joint (Figure 3). Note the wire electrode that follows directly behind the probe.

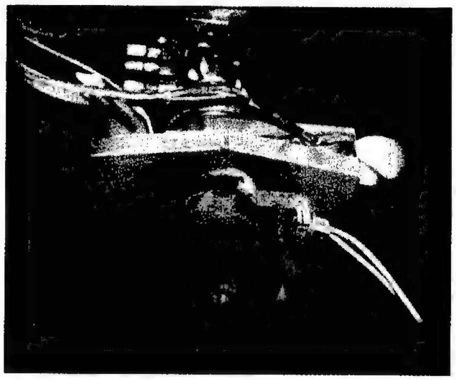


FIGURE 3

- The welding machine, including wire feed mechanism, welding controller, and power supply (Figure 4).

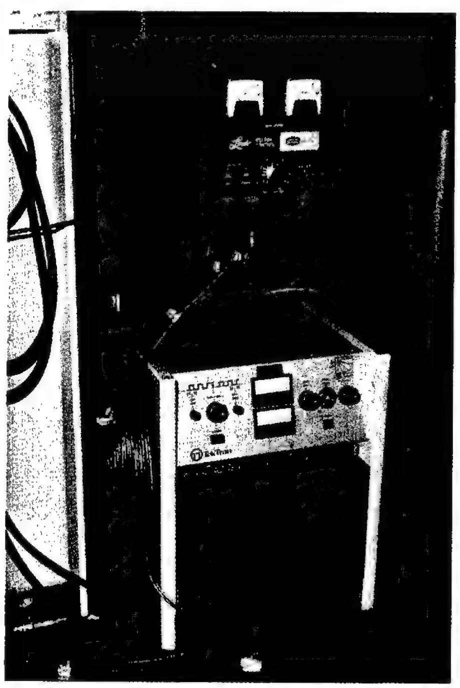


FIGURE 4

- A workpiece positioner that rotates a full 360° on the horizontal and tilts 135° (45° clockwise and 90° counterclockwise) from the horizontal (Figure 5). The positioner work table can carry a 6-ton load.

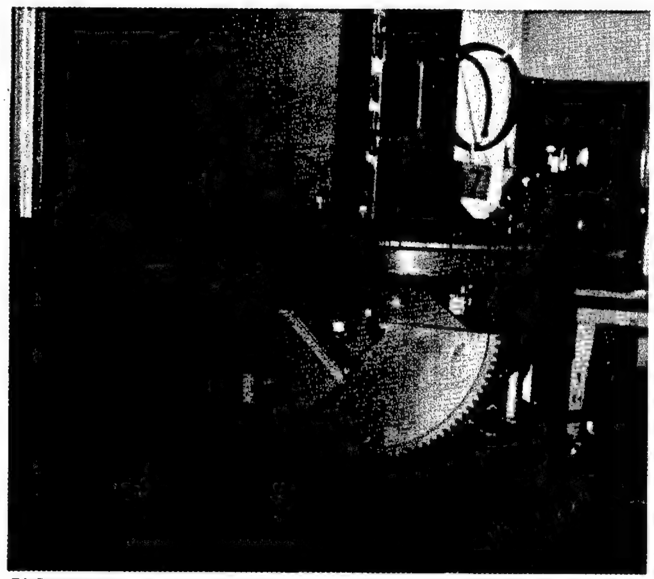


FIGURE 5

- A manipulator, mounted on floor tracks, that carries the track joint welding probe and wire electrode (Figure 6). It can move the probe and electrode in any vertical or horizontal plane.

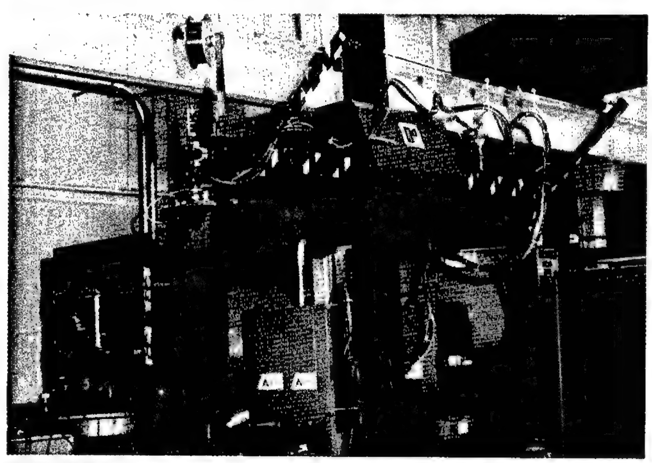


FIGURE 6

- A computer numerical control subsystem that controls all automatic features of the system (Figure 7). It can be programmed for linear speed, direction, and number of passes.

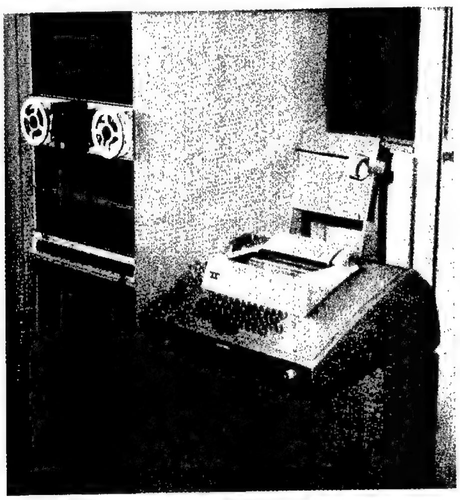


FIGURE 7

Maintains Ideal Welding Position

Figure 8 shows the machine with several of the subsystems in position for a welding operation. The machine maintains an ideal welding position throughout welding; i.e., the probe and electrode are always perpendicular to the joint segment being welded. This is accomplished by mounting the probe and electrode in a permanent vertical position. The positioner then tilts and rotates, under computer control, to keep the joint segment in the horizontal position.

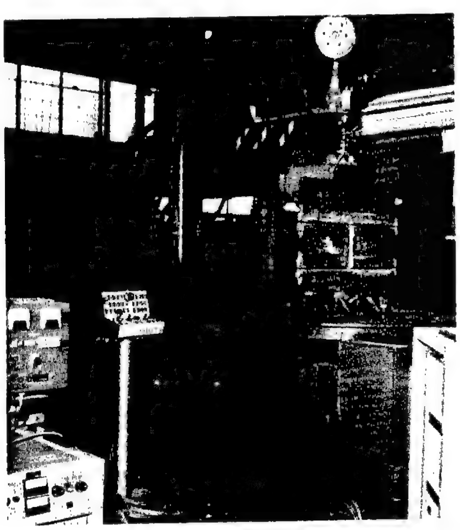


FIGURE 8

This tracking technique is applicable only to magnetic materials; thus TARADCOM's current effort to adapt the tracking controls to aluminum or other nonmagnetic materials.

Obviously, considerable development effort has gone into the machine already. For example, shortly after installation, problems were encountered in the computer's high-speed tape reading system. The problem was quickly attributed to the dusty environment of the welding laboratory and the computer was enclosed in an air-conditioned, dust free room at constant temperature, thereby eliminating that problem.

Two Step Procedure Followed

The automated machine operates in two modes: automatic (probe tracking) and numerical control. The automatic mode, in which the eddy current probe automatically follows the weld joint, is used for the first welding pass. During this pass, the eddy current probe gathers information concerning the location and path of the weld joint in relation to the beginning of the joint. This information is relayed to the computer, which calculates movements of the welding gun necessary to follow the probe down the weld path. The computer guides the gun on the first pass and stores the information. All subsequent passes are made under numerical control using the memorized weld path. This allows much faster welding travel speeds than does the probe tracking mode. The computer memory also allows automatic return of the welding gun to its original starting position along the shortest path. This is extremely useful when welding complicated shapes with complex weld paths.

In the numerical control mode of operation, paper tape is used to instruct the computer. Such instructions might include welding speed, where to start the weld, and how many welds are needed. The numerical control system also tells the operator what functions he must perform in a step by step sequence via the teletype. Consequently, even a layman new to welding could operate the automated welder by simply following the teletyped instructions.

Cost Savings Expected On Tracked Vehicles

Polyurethane Shoes Improve Production Efficiency

To replace a 40-year-old process for compression molding of rubber, TARADCOM has developed a polyurethane track shoe insert for tracked vehicle roadway paths. With an eventual savings potential of over $1 million annually, the processing line and compound recipe are now being put into operation for rebuild production of the M113 family of vehicles. First production will be in Ober Ramstadt, Germany.

The interface between track shoe segments and bogies, or roadwheels, on tracked vehicles must withstand the extreme abrasiveness of dust, sand, grit, and mud. The bare metal surfaces on early tanks had very short useful lives due to the action of these elements. The use of rubberized metal on these surfaces, first on the bogie and, on the track shoes later, has greater increased service life. However, costs have risen as well.

The compression molding process, long used to rubberize track components, requires shipment of track shoes between rubber and metal fabrication manufacturers and use of expensive capital equipment in the molding. The use of castable polyurethanes was investigated in an effort to reduce costs for tracks. The idea was that the urethanes could be applied at the same plant that finish machined the shoe, thus reducing both shipping and actual molding costs.

The process developed at TARADCOM for manufacturing polyurethane shoe inserts uses a compound of Vibrathane B-625 and Vibrathane 3095, Thixon AB-1244 adhesive, and a urethane dispensing machine placed next to a roller conveyor. A production capacity of two shoes or better per minute is possible.

Preliminary cost analysis of the process indicates a savings of about 50¢ per shoe compared to the rubber molding process. While this is only a small percentage of track shoe costs*, if the process is utilized Army wide for both original manufacture and rebuilding of the T130E1 track for M113 vehicles, annual savings could amount to $500,000. If the process is subsequently used for other tracked combat vehicle families, this savings would increase to at least $1 million. Further use of the process will depend on validation of savings as the process is implemented at Ober Ramstadt.

Development Begun in 1972

Feasibility of the polyurethane concept was first demonstrated at Yuma Proving Grounds in 1972 when cast prototypes were tested as track shoes on the M113 personnel carrier. These prototypes performed without failure for 4,600 miles on paved, gravel, and cross country surfaces. Based on this success, an MM&T program was initiated to pursue the concept further. A contract was let to recommend and demonstrate a suitable polyurethane formulation and suitable processing equipment and procedures to produce at least 120 track shoes per hour. Acceptance criteria for the compound were:

- Adhesion to metal—150 pounds per square inch of width (minimum) when tested per paragraph 4.6.1 of MIL-T-11891B.

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*$26.60 for new shoes in the M113 family, $16.00 for rebuilt shoes.

- Hydrolytic stability—a maximum of 30 percent loss in tensile strength after 4 days at 185 F when tested in accordance with ASTM D3137.

Other important considerations included low toxic levels to insure safe handling, low material costs, low compression set, and ozone resistance.

Twelve different formulations were tested to evaluate two classes of polyurethanes—polyether and polyester. From results of tensile, elongation, hardness, tear, and hydrolytic tests on films of each compound, two formulations were selected for evaluation as a track shoe material.*

Compound A (101316 A)	
Vibrathane B-625	100.0
Vibrathane 3080	7.4
Compound C (101316 C)	
Vibrathane B-625	100.0
Vibrathane 3095	12.5

Five adhesives specifically formulated for urethane-to-metal bonding were evaluated and Thixon AB-894, with a minimum peel strength of 214 psi, was selected. Target strength was 150 psi.

Prototype Production Line Set Up

For processing polyurethane shoes, a roller conveyor is placed in front of a urethane dispensing machine, as shown in Figure 1. Trays are loaded with parts at one end of the conveyor, parts are filled with urethane at the center, and the trays are loaded onto a cure truck from the other end. At the loading station, track shoes are secured to a nine-position fiberglass/epoxy tray. The shoes are positioned against stops and a track shoe plug, shown in Figure 2, is inserted through the central hole in the shoe and screwed into the nut. The plug holds the shoe in place and keeps liquid urethane from flowing into the area where the attaching device for the road pad will be located. After cure, the plug is easily removed by hand and is reusable.

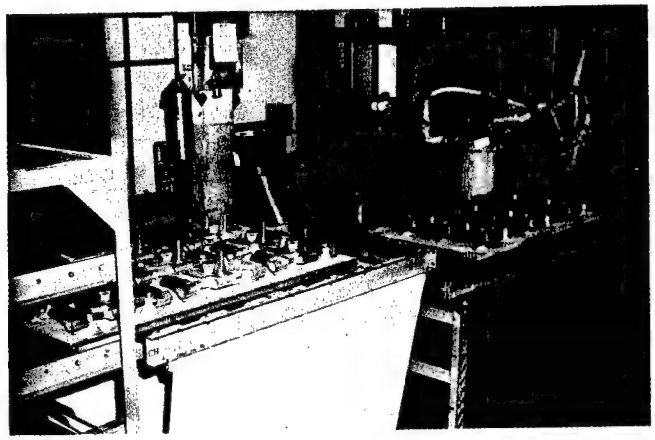

FIGURE 1

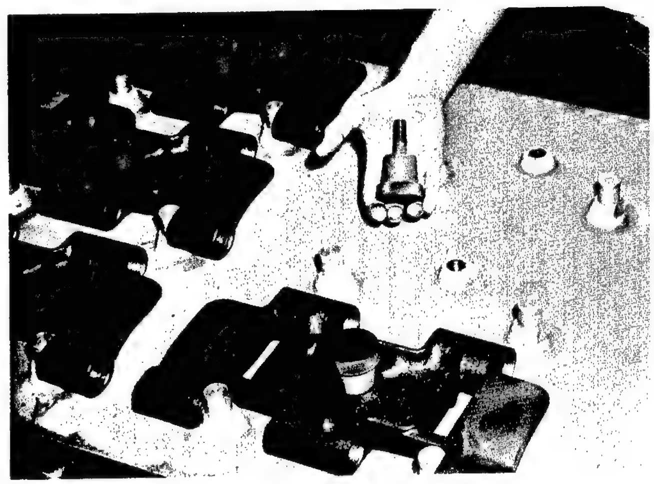

FIGURE 2

The loaded tray is moved to a position under the dispensing head where each shoe is filled with the correct amount of compound, a process requiring about 2 seconds per shoe. When all nine shoes are filled, the tray is moved to the end of the conveyor, where the material is allowed to gel for a few seconds. It is then advanced to the hydraulic lift table and transferred to a truck for transport to the cure oven. A flow diagram of the complete operation is shown in Figure 3.

The first production run of 127 shoes on this equipment included 63 shoes using Compound A and 64 using Compound C. All metal shoes were prepared as detailed in Table 1. Standard T130 E1 shoes were used.

For the run using Compound A, shoes were at room temperature, B-625 was at 200 F, and 3080 was at room temperature. For the run using Compound C, shoes were at room temperature, B-625 was degassed at 210 F, and 3095

*Vibrathane B-625 is a polyether-based urethane; Vibrathane 3080 is Uniroyal's designation for 1-4 butanediol-based curative; and Vibrathane 3095 is Uniroyal's designation for a hydroquinone-bis-beta-hydroxyethyl ether-based curative.

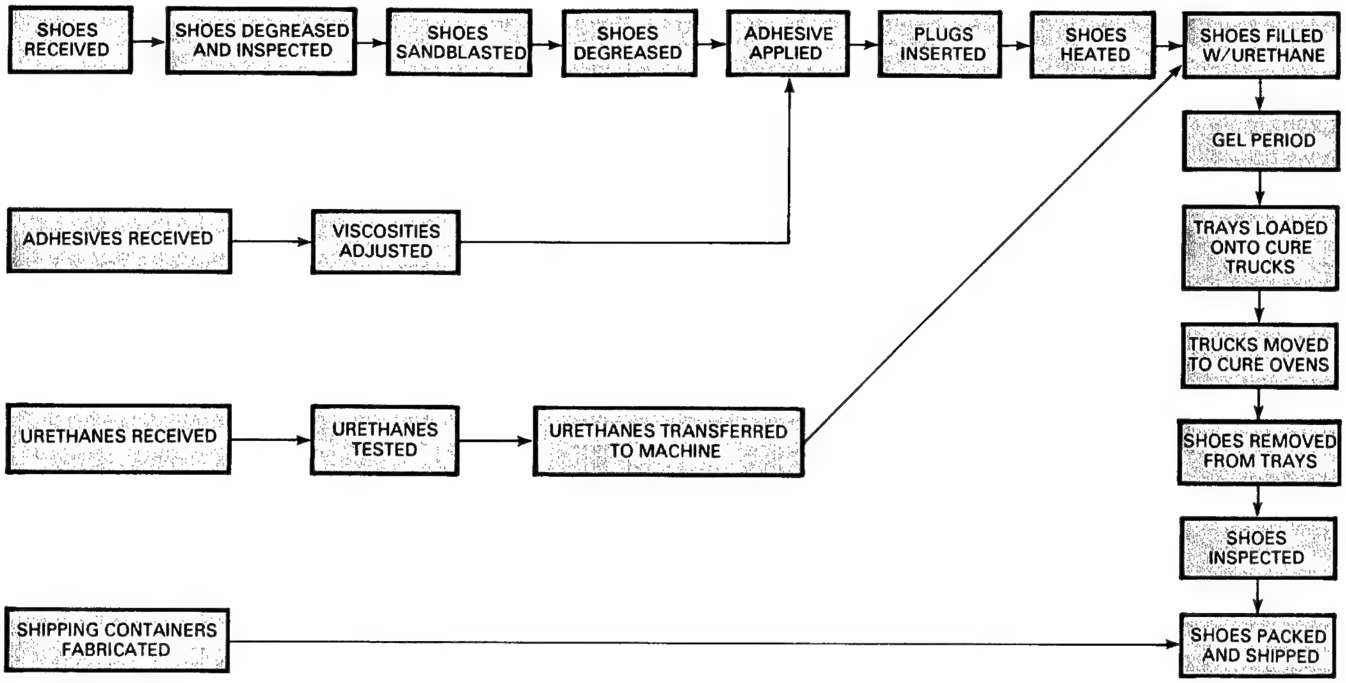

FIGURE 3

was degassed at 230 F. Figure 4 shows Compound C cast on a T130E1 shoe.

The polyurethane inserts were compared with standard rubber inserts during tests on an M113 APC at Yuma Proving Grounds. Tests were conducted on paved, gravel, and hilly cross country courses with 750 miles on each surface (2,250 total miles).

After 1,500 miles of vehicle operation, 50 percent on paved and 50 percent on the gravel tank test course, both of the polyurethane compounds showed approximately 1/16th to 1/8th inch "set" (compression of the polyurethane material) in the road wheel path. Compound C had numerous surface cracks, and Compound A had light chunking in the road wheel path. The standard rubber insert was practically unchanged from its initial condition, the only sign of wear being some light scuffing of the road wheel path. Figure 5 shows the condition of a representative Compound C insert after 1,500 miles.

Table 1. Metal Shoe Processing

1. Completely dip each shoe twice in a container filled with Chlorothene NU degreaser. Let excess solvent drip into container.
2. Completely dip each shoe twice in a second container filled with Chlorothene NU degreaser. Let excess solvent drip into container.
3. Sandblast the 1/2" x 4" x 6" cavity in each shoe with white beach sand.
4. Blow dust from sandblasted surfaces using air that is water and oil free.
5. Temperature of shoes for remaining operations must be at least 60 F.
6. Degrease each shoe cavity with a stream of clean Chlorothene NU. Shoe is to be in a position so that solvent will completely drain from the cavity.
7. Spray one coat of thinned* Thixon AB-1244 in each cavity. Overspray on the rest of the shoe is acceptable. Dry 30 minutes.

*Dilute Thixon AB-1244 to a viscosity of 22 to 26 seconds on a #2 Zahn Cup using the following diluent:

Cellosolve Acetate	60 parts by weight
Methyl ethyl ketone	30 parts by weight
Toluene	10 parts by weight

When adding the diluent, Thixon AB-1244 should be thoroughly agitated with a high-speed propeller type agitator.

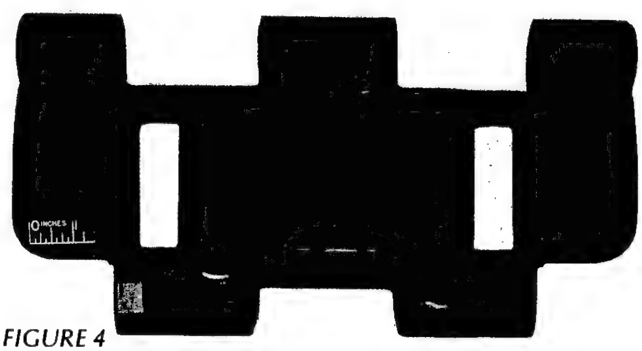

FIGURE 4

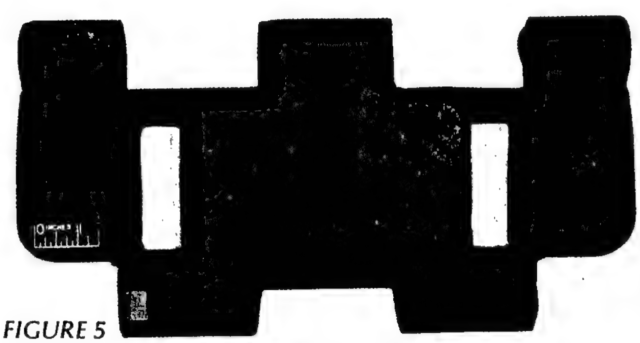

FIGURE 5

Final "Set" Reached

At the conclusion of 2,250 miles of testing, the chunking of the Compound A insert had increased to the point that the entire road wheel path was partially chunked out to a depth of approximately 1/4 inch. The surface cracking of the Compound C inserts had deepened to approximately 1/16 inch, and the "set" in the road wheel path was now approximaty 1/8 inch. A typical Compound C insert after 2,250 miles is shown in Figure 6. The standard rubber control pads remained in essentially the same condition they were in at the 1,500 mile inspection with slight scuffing of the rubber in the road wheel path being the only observable wear.

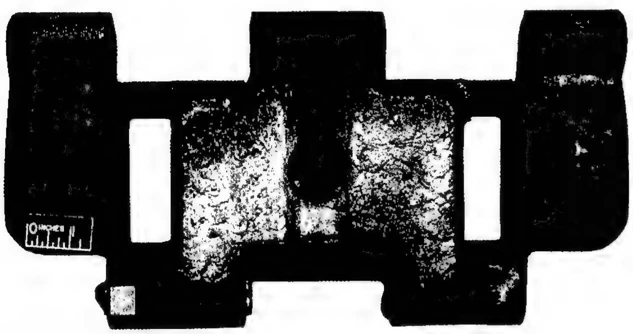

FIGURE 6

Continuation of the evaluation consisted of testing three compounds (C, D, and G)* of polyurethane cast-in-place backing insert equipped shoes and control shoes equipped with the standard rubber backing inserts. Since Compound A had not performed as well as C, it was eliminated from the continuation tests. The tracks were installed on the same M113A1 vehicle.

Although a total of 6,000 miles of operation equally divided between the three test courses was planned, the test was stopped after 4,500 miles since over 60 percent of the test and control shoes had been removed due to rubber bushing failures, and no more test shoes were available. The 4,500 miles that were completed were equally divided between the three surfaces.

Several of the Compound C and control shoes that had accumulated 2,250 test miles (3,621 km) during Phase I were carried over to this phase of testing to monitor the effects of additional operation; however, all shoes were lost prior to the accumulation of 4,500 test miles (7,242 km) due to rubber bushing failures. No additional "set" was experienced during the period of extended testing although more cracking was visible on the Compound C inserts.Figure 7 shows a test shoe after 3,750 miles.

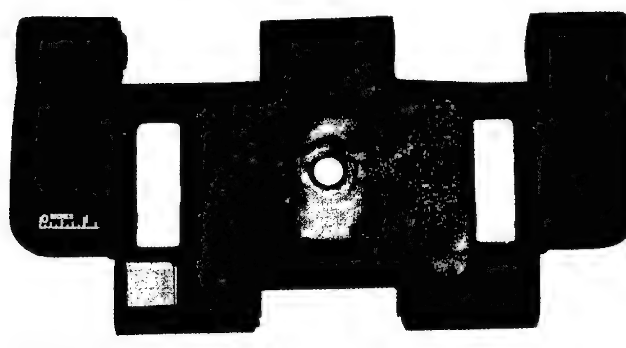

FIGURE 7

Cost Comparison Part of Plan

Although the standard rubber inserts exhibited less wear, Compound C shoes proved their serviceability in these tests and were selected for use in the process implementation at Ober Ramstadt. Part of the implementation plan is a cost comparison to determine actual savings. If the projected cost savings are validated, use of the polyurethane inserts on other vehicle families should follow.

*Compounds D and G (101316D and 101316G) were reintroduced at this time to see if they would have less permanent set than C. Compound D formulation is Vibrathane 6020-100.0, Vibrathane 3080-7.4. Compound G is Vibrathane 6020-100.0, Vibrathane 3095-12.5. Vibrathane 6020 is a copolyester-based urethane.

Costs Lowered, Serviceability Maintained

Automotive Gears From Powder Metallurgy

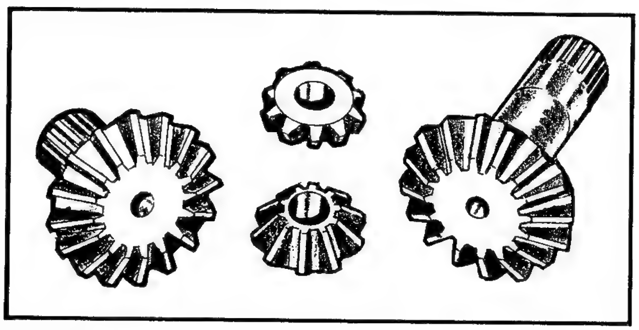

FIGURE 1

Powder metallurgy (PM) may be the wave of the future in the manufacture of automotive components for high-performance applications. Prototype differential gears for the M151A2 1/4-ton truck forged from powder metal for TARADCOM cost from 23 to 35 percent less than conventionally processed parts. For the differential alone, this represents a savings of $21,000/yr for pinion gears and $41,500/yr for side gears. These PM gears have satisfactorily completed as much as 22,000 miles of road testing. Furthermore, the PM techniques developed for these gears provide a basis for expanding the use of powder metallurgy to larger and more complex parts. This would result in substantial cost savings on many other tank automotive components.

The process utilizes forging of porous powder metal preforms in hot dies (PM forging). This allows the manufacture of forged components without flash (waste metal) or draft angles—the taper normally given to a die so that the work can be easily withdrawn. This precision process results in considerable material savings and eliminates many secondary machining operations.

The hot forging process selected for producing PM gears at TARADCOM employs a simplified preform configuration which requires a three dimensional type of metal deformation during the forging process.

TARADCOM chose gears used in the differential of the M151A2 as models for investigating the PM forging process. The objective was to demonstrate the feasibility of using lower cost forged powder metal gears in a critical, highly loaded application.

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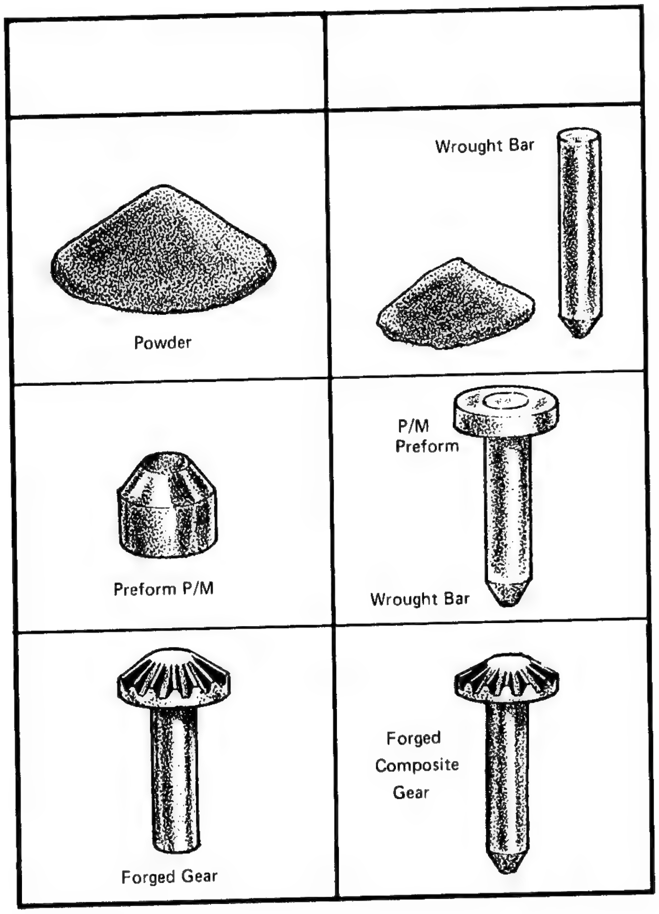


FIGURE 2

TRW was selected to investigate process variables and to produce prototype PM gears. They had previously developed a PM forging process for manufacturing high performance gun components for the Army Weapons Command at Rock Island. That program demonstrated that PM forged components with fatigue and impact strengths comparable to wrought material could be produced at a significantly lower cost.

Two Fabrication Methods Used

Two differential side gears and the mating pinion gears were used in the investigation. These are shown in Figure 1. On the left is a side gear 2-3/4 inches long with bevel gears on a 2-3/4 inch outside diameter flange at one end and a spline at the other end. The other side gear is longer—about 4-3/4 inches, with the pinion gears in the center. These wrought differential gears are made from a high strength forging grade steel.

TRW's task was to develop a production process from powder to preform to the finished part. Two methods were investigated for producing the prototype differential side gears: (1) forging of a single part from a powder metal preform and (2) fabrication of a composite form consisting of a round wrought steel bar forged into an integral unit with a PM preformed toothed gear section (Figures 2 and 3).

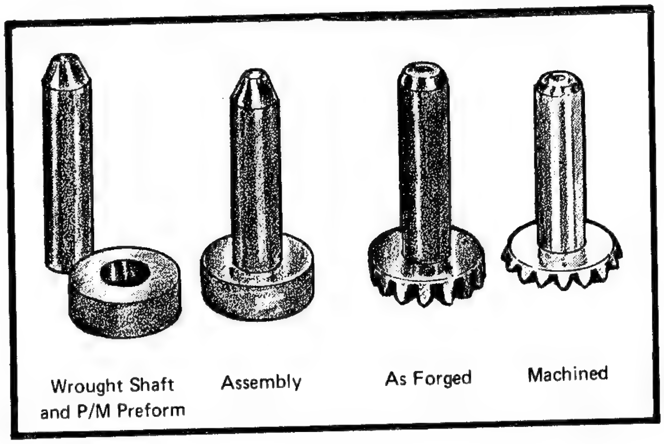


FIGURE 3

The composite or press bonded gear fabrication concept was introduced as an alternative method of forming the shaft section of a gear. This procedure is applicable to shafts of various lengths and insures full density in even the longest shaft. The concept also adds the advantages of composite materials to gear fabrication where the shaft and gear materials can be tailored to the best advantage of each material.

Similar Powders Analyzed

Three types of prealloyed commercially available steel powders were investigated to determine which would provide a serviceable gear at the least cost.

A particle shape analysis was performed by scanning electron microscope (SEM) analysis. The basic particle shapes of all three samples were found to be similar—a mixture of distorted flattened or distorted elongated spheres. The shape and size distribution of these powders contributes to high strength by providing interlocking of particles during compacting operation.

The powders were inspected for cleanliness, homogeneity, grain size, and hardness as depicted in Table 1. All the materials showed a clean microstructure; i.e., a minimum of foreign particles. The majority of the particles were fine grained and of sufficient softness to provide a readily compactible material. Chemical analysis of the

Table 1

Vendor Designation	Median Particle Diam., microns	-325 Mesh, Fraction %	20–80% Size Range, microns	Grain Size ASTM No. Range	Grain Size ASTM No. Average
4600	68	25.0	41–110	6.5–10.5	9.0
46F2	50	40.0	24–95	7.5–10.5	8.8
40F2	65	28.0	40–104	6.5–10.0	8.0

three powders is given in Table 2. The materials were characterized by particle size and shape analysis and by metallographic examination. They proved to be similar, and all three were acceptable on the basis of these characteristics. Because of their similar hardenability and freedom from the constituents which form oxides that are difficult to reduce, all three were selected for further evaluation. All were priced in the 20 to 25¢ per pound range at the time the project started.

Table 2

Element	4600	46F2	40F2
Mn	0.20-2.25	0.35-0.40	0.50-0.59
Ni	1.25-1.90	0.30-0.45	—0.06
Mo	0.38-0.50	0.45-0.55	0.43-0.55
O_2	0.10-0.16	0.12-0.13	0.12-0.13

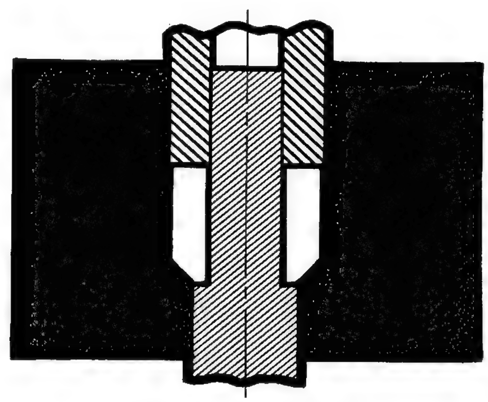
Material Selected on Hardenability

To further evaluate the materials, sintered rectangular specimens were forged at combinations of three different preform forging temperatures and three different die temperatures. Samples were first compacted and sintered at 2050 F, then were preheated to 1600, 1800, or 2000 F and forged at die temperatures of 300, 450 or 600 F. Next, the samples were heat treated and sandblasted and their densities were measured. The density measurements indicated that, for the minimum deformation type of specimen used, the effect of die temperatures on end point density was minimal; the preheat temperature appeared to be a more important variable. At 2000 F, densities of all three materials closely approached theoretical maximum, with much less scatter than at lower preheat temperatures. This indicated that a preheat temperature at least this high is required to consistently produce high density forgings.

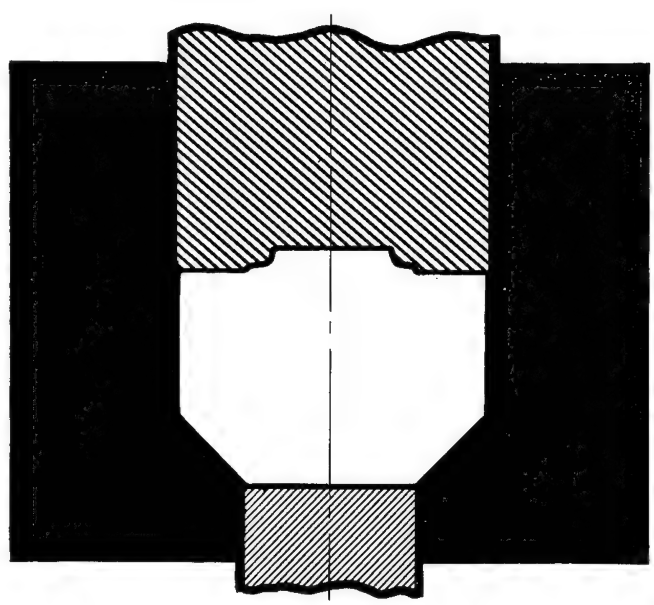
Results of metallographic examination of forged gears made from the three prealloyed powders favored the 4600 composition. Its hardenability was better suited to gear production, a broader background on its processing data was available, and it did not exhibit the coarse grained skin effect found with the other two specimens. Accordingly, the 4600 composition was selected for the remainder of the investigation.

Preform Density, Not Shape the Key

Hot forging tooling was used for the gears. This tooling was designed for forging with a single blow without flash or draft angles and for producing finished gear teeth without machining. While the side gears would require machining of the back face and shaft, the pinion gears would require



Pinion Preform Tooling

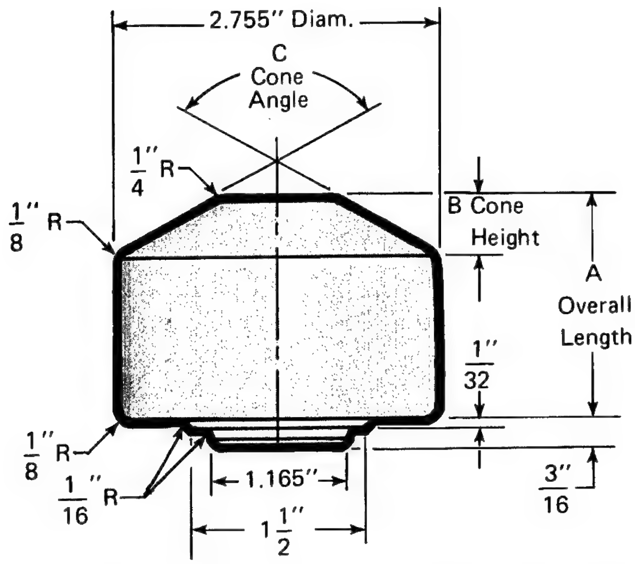


Gear Preform Tooling

FIGURE 4

none at all. Figure 4 shows the side gear and pinion gear preform tooling design.

Sample gear and pinion preforms were processed to investigate and optimize the processing parameters. The investigation first showed that a minimum preform density of 83 percent was required to avoid cracking of the teeth in the subsequent forging process.

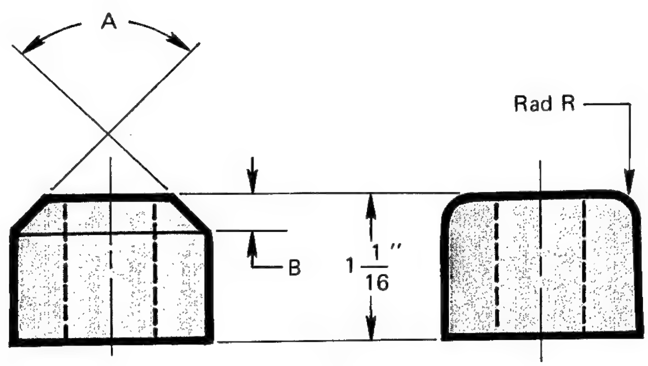


Detail No.	A Overall Length, in.	B Cone Height, in.	C Cone Angle, °
1	2.230	1-1/4	60
2	1.900	3/4	60
3	1.710	1/4	60
4	2.235	1	90
5	2.025	3/4	90
6	1.850	1/2	90
7	1.730	1/4	90
8	2.170	3/4	120
9	1.940	1/2	120
10	1.760	1/4	120
11	1.710	0	180

FIGURE 5

The effects of varying the side gear preform cone angles from 60 to 180 degrees, cone height from 0 to 1¼ inches and overall height from 1¾ to 2¼ inches were also investigated (Figure 5). This was done by machining the initially produced preform to the desired configuration and subsequently forging it into the finished shape. None of the preform configurations had a noticeable effect on forging results or the forging action. It was found that forging the optimum gear preform shape in a hydraulic press at 25 tons per square inch and 2200 F produced finished forgings with 99.5 percent of theoretical density.

Similar work was conducted on the pinion gear forging (Figure 6) to optimize the preform configuration and establish the preform weight and also weight tolerance. Cone angles from 60 to 120 degrees and cone heights from 1/8 to 1/4 inch were investigated. Forging trails on the pinion gear preforms showed that a density of 99.5 percent of theoretical was obtained at 40 tons per square inch and 2200 F. The difference in pressure was attributed to ths relatively small mass and large surface area of the pinion gear compared with the side gear forging.



Spec. No.	Angle A, °	Width B, in.
1	120	1/8
2	120	1/4
3	90	1/8
4	90	1/4
5	60	1/8
6	60	1/4

Spec. No.	Radius R, in.
7	1/32
8	1/8
9	1/4

FIGURE 6

Forging in a 500 ton, crank type mechanical press with a range of 15-30 strokes per minute was also evaluated. Gears with 99.5 percent density were produced. There were no areas of undesirable metal flow cracks or dead areas in these forgings. Variations in press speed had no visible effect.

Good Mechanical, Metallurgical Properties Achieved With PM

Rectangular mechanical test specimens were processed using the same parameters as those used in processing the gears. Tensile, fatigue, and impact properties were tested. All test results showed acceptable properties.

In addition, several of the composite PM side gears were torque tested to failure and compared with similarly tested conventional gears of the same dimensions. Test results showed the wrought shaft to have been satisfactorily integrated to the PM portion during the forging step. No further testing was performed on the composite gears.

Completion of this work led to the development of a preliminary process specification. Using this, 100 gear sets were produced for metallurgical evaluation and vehicle testing.

The metallurgical evaluations included a comparison with wrought 4620 steel. The PM forged material was free from porosity. Both materials exhibited few inclusions, although the PM parts had more. The forged gears were sectioned to show the material flow in the critical areas of the gear tooth form. The macrograph in Figure 7 indicates that a favorable flow line pattern parallel with the tooth form is present, particularly in the fillet areas. The P/M forged material had a coarser grain size, which was attributed to the high processing temperature used for sintering and forging.

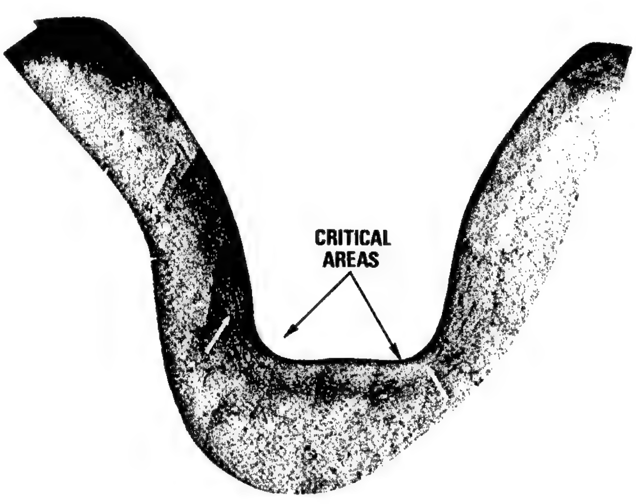


FIGURE 7

Gears Tested OK on Vehicles

The gears were installed in seven M151A2 vehicle differentials and tested at Yuma Proving Grounds in Arizona. The test course covered paved roads, secondary roads, and cross country terrain. Payloads, towed loads, and speeds in accordance with vehicle specification were used. Four of the vehicles completed 10,000 to 12,000 miles of testing and three completed 20,000 to 22,000 miles. All of the gears performed satisfactorily. Tear down inspection showed that on only two gears were small chips removed—from the outer surface of the teeth near the heel. This had no effect on serviceability. Based on these tests, the PM gears were judged suitable for vehicle application.

23–35% Cost Savings Seen

The primary cost advantages of the PM forging process over the conventional process for producing differential gears lies in better material utilization and significant reduction of machining operations.

Production quantities of 200,000 units/yr and material costs prevalent in 1974 were used in this analysis (Table 3).

Table 3

	Pinion Gears		Side Gears	
Item	Conventional	PM Forging	Conventional	PM Forging
Material	$0.143	$0.056	$0.646	$0.450
Forging	—	0.488	0.508	0.508
Machining	0.539	0.058	0.762	0.724
Gear Tooth Cutting	0.260	—	0.420	—
Finishing	0.055	0.055	0.414	0.414
Total	$1.00	$0.66	$2.75	$2.10

Cost reductions of 23 percent were projected for the PM side gear, which requires some machining, and 35 percent for the PM pinion gear, which requires no machining. Based on the results of this analysis, the PM process could produce gears at substantially less cost than conventional processes.

Acknowledgements

The sources for this article were (1) TACOM Technical Report No. 11960, *Forged Powder Metal Gears,* by F. T. Lally and I. J. Toth, TRW, Inc. and (2) YPG Test Report No. 233, *Forged Powder Metal Gears Test for M151A2 Differentials,* by John C. Holman.

Reduces Weight, Improves Performance

Aluminum Used For

Combat vehicles equipped with lightweight aluminum track block developed for TARADCOM have shown marked improvement in acceleration and drawbar pull performance. The new track has provided improved acceleration—as high as 29 percent—and a 3200 lb improvement in drawbar pull at 22 mph. Manufacturing costs and fuel consumption remain about ths same as for steel track vehicles. Furthermore, the aluminum track has exhibited satisfactory wear through 8000 miles of testing.

Data from recent tests of a prototype XM1 tank equipped with similarly designed tracks supports these results. Though limited, these combined tests show that the lighter aluminum tracks give combat vehicles the mobility and maneuverability essential to effective battlefield performance.

Although high mobility and maneuverability are essential in engagements involving armored combat vehicles, these attributes are increasingly negated as the weight of the armor and of the vehicles increases. To counter this, efforts are continually being made to reduce vehicle weight wherever possible, without degrading its armor and thereby its resistance to antitank fire. The track system accounts for an appreciable portion of the total tracked vehicle weight (about 9 percent for the M6OA1 tank), thus it is a prime target for weight reduction.

Therefore, a program was undertaken to develop a forged lightweight aluminum track block for a medium tonnage combat vehicle. A study made some time ago indicated that forged aluminum track block, to replace present steel versions, could withstand the high stresses experienced during extreme maneuvering.

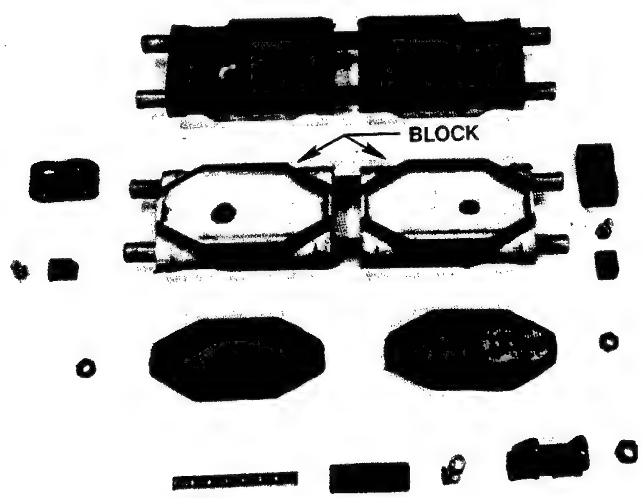


FIGURE 1

The track block is a component of the standard steel T142 track shoe assembly, a disassembled view of which is shown in Figure 1. The steel block was replaced with an aluminum forging, but all other parts of the shoe remained standard. The track shoe with the aluminum block is completely interchangeable with the standard steel shoe but, because it weighs 25 percent less, it reduces total vehicle weight by approximately 2,200 pounds.

TRACK FABRICATION

Fabrication procedures for the aluminum track were as follows:

(1) All track blocks were fabricated from 2014 aluminum alloy and forged from 4 1/2-inch-diameter stock in three forging operations.
(2) After forging, a very hard aluminum alloy was welded to the tops of grousers, or a portion of them, in an effort to enhance their wear resistance. (Grousers are that portion of the block that contacts the road or ground surface.) This coating, designated M645 alloy, was developed by ALCOA for such applications. Its composition, in weight percent, is silicon 20, copper 15, manganese 4, iron 2, and aluminum 59.
(3) All forgings were heat treated and aged to a T61 temper.
(4) Machining consisted of drilling the track pinholes and facing both ends of the block.
(5) All the forgings were rubberized and assembled into shoes.

ENDURANCE TEST

Two separate vehicle tests, using M60A1 tanks, were conducted on the track at the Aberdeen Proving Grounds. Results were evaluated and compared with previously accumulated data on the standard T142 steel track.

The test course consisted of equal portions of paved, gravel, and cross country terrain. Mileage distribution and average vehicle speeds compiled for 3545 test miles during the first test are given in Table 1. Operation was in in-

TABLE I. Operational Data

Course	Miles	Average Speed, mph
Paved	742	23.4
Gravel	1183	20.9
Cross Country	1620	12.1
TOTAL	3545	17.4

Vehicle Tracks

KEROLD F. CHESNEY also served as author of an earlier article in this issue of the *ManTech Journal*—**Automotive Gears from Powder Metallurgy**. His key role in the development of these two new manufacturing techniques illustrates his versatility as a Materials Engineer. As such in the Armor, Material Application Technology Function at TARADCOM, he continues to serve as Project Engineer on numerous projects involving new materials utilization.

crements of approximately 150 mile cycles until each test was completed.

For the first test, one side of the vehicle was equipped with a set of hard coated aluminum shoes and the other side with the set of uncoated shoes. This test was terminated because roadwheel failure in the early stages of the test had inflicted extensive damage to the entire track.

For the second test, the vehicle was equipped with hard coated shoes only. This test ran for 8,500 miles, at which point the track assemblies had reached their operational limit. Two track block failures occurred in the pinhole area, one at 1,500 miles and the other at 7,800 miles. Subsequent examination of the block failures showed that both were fatigue fractures.

Acceleration, drawbar pull, and fuel consumption tests were also performed, both on vehicles equipped with standard steel T142 track and on the test vehicles, to compare other performance characteristics.

The aluminum track improved the acceleration performance of the M60A1 vehicle by 10 percent in the 0 to 10-mph speed range, 20 percent in the 10 to 20 mph range, and 29 percent in the 0 to 32 mph range.

The drawbar performance tests were conducted on smooth, dry, level pavement utilizing a mobile dynamometer and associated instrumentation. There was no significant effect upon the low transmission range drawbar performance of the M60A1. However, high range drawbar pull attained with the aluminum track was increased by 1,700 pounds at 5 mph and by 3,200 pounds at 22 mph over that obtained with the steel track.

Standard fuel consumption for the M60A1 was not significantly different. Over a road speed range of 10 to 23 mph, fuel consumption varied from 0.60 to 0.67 mpg for the aluminum track and from 0.60 to 0.64 mpg for the T-142 steel track.

Problems Encountered in Testing

Several problems were encountered during the tests. For example on several of the track shoes, the rubber track pin bushings extruded around the pinhole, and this broke the bond between the pin and the rubber bushing, allowing the block to shift. The shifting of the track block caused the pins, center guides, and end connectors to become misaligned. It was first thought that the loosening and shifting problem was peculiar to the aluminum track; however, recent tests have indicated that the problem also exists in the steel T142 track, but to a lesser degree. Also, during the initial stages of the test, pads were lost by the pad bolt pulling through the aluminum block. This was rectified by placing a washer under the head of the bolt to distribute the load.

Wear Results

During the test, the track was inspected periodically to determine the extent of wear on the track components. The results were as follows.

- In the first vehicle, average wear after 2,000 miles measured 0.11 inch on the track block grousers of the hard coated shoes, as compared with 0.05 inch on the uncoated shoes. The higher rate of weight loss on the hard coated shoe appeared to be from chipping of the hard coat surface rather than from abrasive wear.
- At the end of 2,000 miles with the second vehicle test, the grouser wear averaged 0.06 inch. After 5,000 miles of service, the track was still in serviceable condition, the track block grouser having worn down approximately 0.25 inch. The integrity of the track block was excellent. Figure 2 shows the track with its rubber pads removed after 5,000 miles of test.

FIGURE 2

- At the completion of the second test, the integrity of the aluminum track blocks was satisfactory, with the exception of one block which contained a pin tube fracture. The average grouser wear was approximately 1 inch. The excess wear was partially due to failure to replace the rubber pads when they were worn in excess of serviceable limits. Normally the pads are replaced at approximately 2,000 miles; however, in this test, they were intentionally run for 3,500 miles in order to give the grousers more exposure to surface wear.

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Track Shoe Forgings Via Computer

Die Design and Manufacture Given Assist

A computerized method for designing and manufacturing track shoe dies for military combat vehicles shows equal promise for designing dies for a wide variety of other forgings. Using the system of computer programs called TRACKS, TARADCOM has successfully designed blocker and finisher dies for forging track shoes and links. The program also assists in manufacture of the dies by numerical control (NC) machining techniques. TARADCOM has verified the computer aided design and manufacturing (CAD/CAM) method on both T130 and T142 track shoe forgings.

One major track shoe manufacturer has investigated TRACKS with encouraging results and is now considering its implementation into the manufacturing process. Furthermore, program results at TARADCOM indicate that the technique can be applied to the design of dies for many other nonsymmetric forgings, provided that the die can be designed by analyzing the forging cross section by cross section.

Interactive Operation

Figure 1 outlines the TRACKS system, which was developed with the assistance of Battelle Columbus Laboratories. TRACKS is a totally interactive system requiring an experienced die designer. However, it greatly increases the designer's productivity by allowing him to evaluate a number of alternatives in a fraction of the time now required. TRACKS is implemented on a stand alone minicomputer system equipped with a refresh graphics display and light pen.

The designer initiates the process by feeding the computer a file of coordinates describing each cross section of the forging. The computer calculates the geometric properties (area, volume, centroid, etc.) of each section and asks the designer to indicate the next function to be performed. Among his choices are stress analysis and

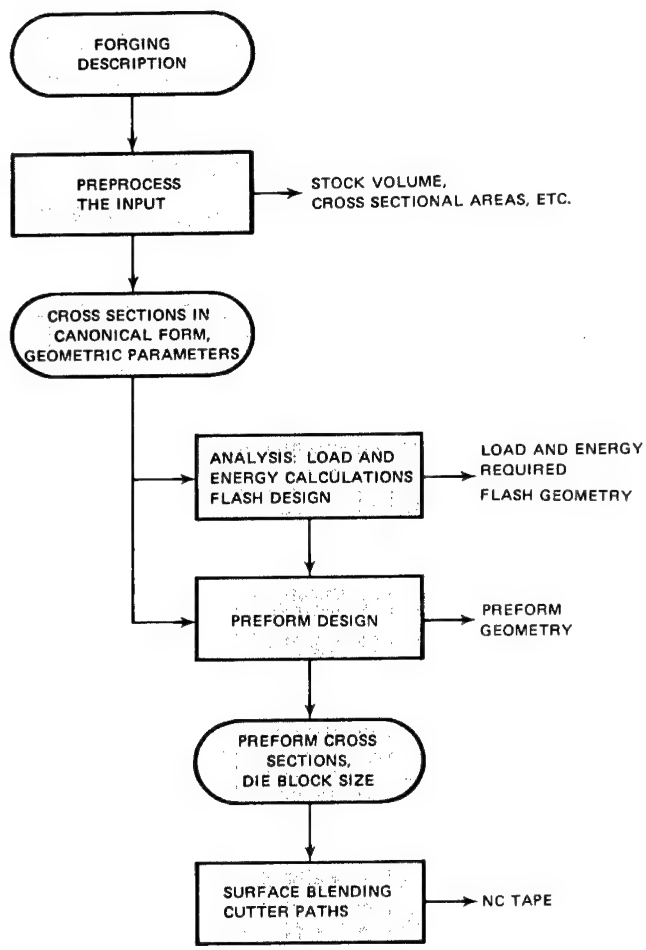

FIGURE 1

preform design. When requesting stress analysis, the designer indicates with the light pen the location of cavities on the section across which metal flow will occur in shear. The system then displays the metal flow surfaces based on the designer's input and calculates and displays the stress-distribution curve for the section. The values generated include maximum stress, total load, average forging pressure, and the center of load on the section.

If the designer is satisfied with these values, he may save the coordinates describing the die section, which now include flash coordinates. If he does not like the results, he may specify new flash parameters and repeat the calculations.

When selecting the preform design option, the designer can first modify the section by adding or deleting certain geometric elements. When he has made the desired modifications in the preform polygon, the designer requests a display of the modified shape and enters the second stage of preform design. In this stage, he may separate the images of the upper and lower dies, and then position the image of the preform so that it just nests into the dies. In this way, he can readily visualize how the preform will physically fit the finish die just before the finish impression is made.

When load analysis and preform design have been completed for all sections, the CAM phase of "TRACKS" is used to prepare a tape for NC machining of a model or an EDM (electrodischarge machining) electrode of the preform. The user specifies the position and thickness of the various sections, as well as machining parameters such as cutter size and draft angle. The computer then calculates the cutter center line coordinates for the path which will generate the desired surface. The program uses numerical techniques to provide smooth blends at the transition from one section to another. The graphics display allows the cutter paths to be viewed before a part is cut. This allows the NC results to be checked for obvious errors and permits modifications before a large amount of time is spent in the actual machining operation. A wood model of the preform for the upper half of a T130 track shoe for the M113 armored personnel carrier, made using the "TRACKS" system, is shown in Figure 2. Some background on this system and its development help to further define its purposes and functions.

Die Design Time Consuming and Costly

First, there was an obvious need for a computer program such as this. Many of the Army's vehicles use a

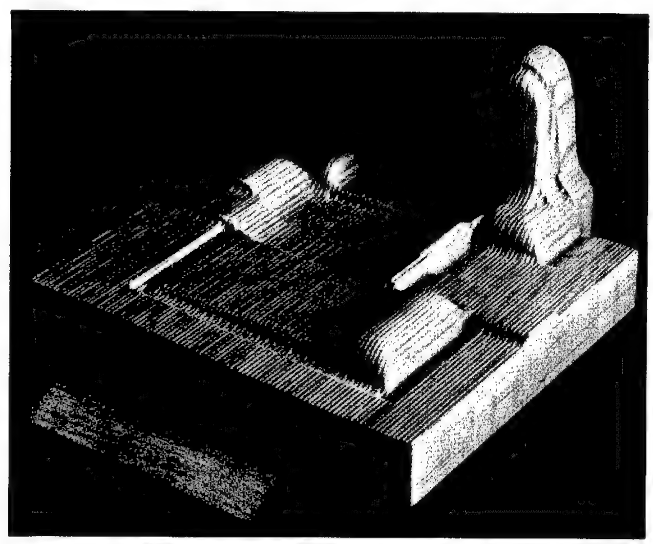

FIGURE 2

large number of track shoes and links. These items are made from various steel alloys by closed die forging, followed by finish machining. A considerable portion of their manufacturing cost is incurred in producing the die sets for forging (generally both roughing and finishing dies are needed) and in the material scrap resulting from the forging flash. Excessive die wear and unexpected breakage often add to these expenses.

Proper design of the dies, especially the roughing or blocker set, is highly dependent on the skill and experience of the designer. After completing a best judgment design, he makes a model in wood, plastic, or plaster by hand. A tracer milling machine traces the model to produce the die cavity, or an EDM electrode from which the die is to be made. These various steps require skill and experience on the part of the craftsmen and can take considerable time. After the forging dies are completed, additional time and money are needed to test and refine their geometry. This great expense results from the complexity of the design process.

Among the factors considered, or calculated, in designing a forging die are the forging volume and weight; the volume distribution; flash dimensions; flash and scale losses; loads, stresses, and energies to be encountered; and the selection of forging equipment. A designer must consider these same factors for both preforming (often more than one) and finishing operations. The designer generally computes variables, such as the volume or volume distribution, by dividing the part into basic geometric shapes (spheres, cones, cylinders, rectangles, etc.) for individual evaluation. Such procedures are lengthy and inexact at best and provide many opportunities for human error. For other variables, the designer relies strictly on judgment and experience.

Another factor in the complex design process is the selection of equipment and and the positioning of the dies under it. The designer must predict (a) the maximum forging load, (b) the forging energy, and (c) the center of loading in the die. Determining the center of loading reduces off center loading and improves tolerances in the forged part.

These many variables are determined much more efficiently and accurately with computerized procedures. Once the preforming and finishing dies are designed, computer techniques also allow more efficient manufacturing of the dies by NC machining. Thus, die manufacturing costs are lowered and die precision is improved.

Previous studies had adequately demonstrated the successful application of CAD/CAM techniques to families of parts, such as turbine and compressor blades. The computerized methods reduce the amount of judgment required to produce forging tools, result in lower tool manufacturing costs, and produce better finished parts with less scrap losses.

Despite the feasibility, a lack of well established quantitative engineering methods has limited the use of computers in forging applications. Recently, however, designers have used computers increasingly to solve technical problems in forging process design and die manufacturing. Some of these applications are already routine operations in forging plants; others are used only at research and development laboratories or on an exploratory basis. Some uses of computers in forging include computer aided cost estimating—where weight of stock, cost of die manufacturing, cost of auxiliary operations (such as shearing and heating of billets, trimming of flash, heat treating, cleaning, and inspection of forgings), and cost of forging operations are determined by a computer program:

- Computer prediction of load and energy requirements for a given operation
- Computer aided design of selected preform cross sections
- Numerical drafting and NC machining of templates

- NC machining of forging dies or graphite electrodes for EDM of the dies.

Recently, the Air Force Materials Laboratory sponsored a Manufacturing Technology Program on the "Application of CAD/CAM Techniques in Forging of Aircraft Structural Parts". During this program, they developed a computer aided method to design the preforming and the finishing dies and to NC manufacture the forging dies.

This prior work was very useful in formulating the conceptual approach to computer design of track shoe forging dies. Contrary to aircraft structural parts, however, track shoes do not exhibit geometric modularity and their analysis and preform design require a more global approach.

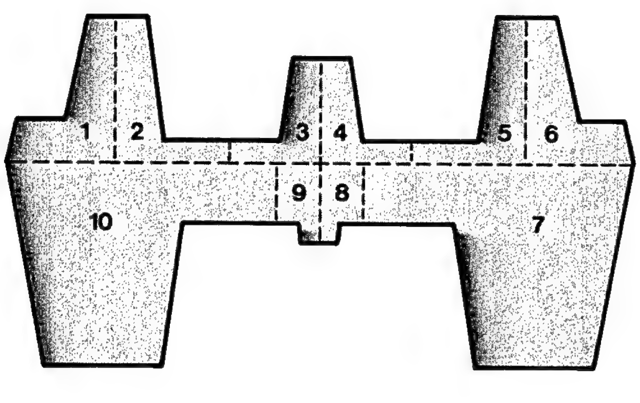

FIGURE 3

Computer Aided Design of Preforming Dies

Preform operations, also known as blocking, are intermediate steps needed in many closed die forging operations in order to insure adequate metal distribution. Only with proper preform design will the final forging operation achieve defect free metal flow, complete die filling, and minimum flash loss.

In many forge shops, preform or blocker die design is based largely on intuition and empirical guidelines. Recently however, preform design has been computerized for rib web type forgings.

A detailed review of many rib web type structural parts reveals that almost all structural cross sections can be divided into basic components of L shapes. This is shown in Figure 3, where ten different L shapes form the cross section of a forging. Hence, once a generalized design procedure for the basic L shape is set up, the computer aided technique can easily combine the basic modules in a building block manner to obtain preforms for many parts. Further, by modifying certain design parameters, such as the ratio of the web thickness of the preform to that of the finish part, different preform shapes can be designed for different materials to be forged in different forging machines.

Track shoe cross sections, however, do not exhibit the modularity of most structural parts. Therefore, it is necessary to assume a global approach to preform design and consider a given cross section as a whole. Through a literature survey, finish die designs were compared to the corresponding preform designs in order to develop mathematical guidelines suitable for automating preform design. These guidelines usually yield an acceptable preform, but not always. Therefore, extensive interaction capability was provided so that the designer could apply his experience to the computations to obtain an acceptable

preform. The computational speed of the computer and the visual perception of the designer complement each other in producing a preform design.

Finish Dies With Proper Flash

Apart from the geometry of the forging, the flash configuration determines the finish die geometry. Flash dimensions directly influence the stresses and loads encountered by the dies during forging. When the stresses exceed the allowable levels, dies either crack or deform permanently. Stress distributions and peak stress will vary with flash width and thickness; a thicker flash or a shorter flash will result in a lower peak stress.

Proper flash dimensions result from a compromise between the maximum allowable stresses on the dies, the capacity of available equipment, and the amount of excess flash material needed to fill the die. The best compromise is reached using an interactive graphics terminal that displays the stress distribution and the average pressure, as seen in Figure 4 for a track shoe cross section.

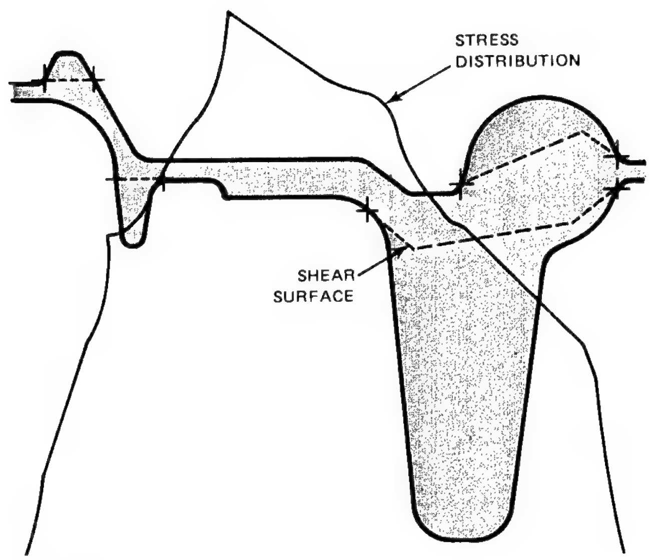

FIGURE 4

Forging Dies by NC Machining

Forging dies, or the electrodes for EDM of these dies, are usually made by copy milling. This requires that a skilled model maker first make a model from wood, plaster, or plastic. At the present state of the art, NC machining of dies is most economical for parts of the same geometrical family and for certain symmetrical parts. The economics of NC are apparent especially when NC and conventional die-sinking techniques can be combined. In this case, most of the die surface is machined by NC while detail machining of the corner or the fillet radii is done conventionally.

NC machining becomes much more practical when preform design is performed via computer programs. It then becomes economically attractive to go one step further and produce a tape for NC machining of the preform surface. This economic advantage arises from the fact that the geometry is already in computer readable form and is defined by cross sections which are to be "blended" by the model maker. Thus, a generalized blending algorithm can take care of most of the surface.

As noted earlier, the computer method described here is not limited to track shoe forgings. This system of computer programs is very flexible and can be applied to a variety of other forgings. The system is available to any interested U.S. company as are a final report and 12-minute, 16mm film describing the process. The film and report are available on a loan basis from TARADCOM, DRDTA-RKA, Warren, Michigan 48090, or AMMRC, DRXMR-ER, Watertown, Massachusetts 02172.

Major Cost Drivers Critical

Cost Analysis = Best Deal

Getting a handle on production costs—that's what's happening for the Tank Automotive Research and Development Command (TARADCOM) thru its Systems and Cost Analysis Office. The Office uses a three pronged attack (data collection, automated retrieval, and economic analysis) to accomplish its mission—which is to accurately assess the true cost/benefit relationships between current manufacturing technologies and new or improved ones. Cost Analysis personnel consider identification of major cost drivers as the most critical element in meeting this challenge—critical in fact to the entire ManTech program of this Command.

Data Acquisition, Identification, and Analysis

In fulfilling a major role of support to the TARADCOM ManTech program, the Systems and Cost Analysis Office ties together three important interrelated elements:

(1) Design and implementation of an automated cost information system for large volumes of data on major tank automotive systems/components

(2) Identification and analyses of the major cost drivers in the production and support of Army tank automotive systems/components

(3) Economic analyses assessing the potential payback from proposed projects by use of a new or improved manufacturing technology.

Rapid Access Provided

The basic purpose for designing and implementing an automated cost information system (see (1) above) is to provide rapid access to cost breakdowns of major systems/components according to piece parts. These breakdowns include costs of unit parts required to procure end items, plus the separate parts costs required to support operational systems/components. These parts costs may be organized in a number of ways—e.g., according to Mil Std 881A, "Work Breakdown Structure for Surface Vehicle Systems", or according to material and labor process cost subdivisions, etc. In total perspective, however, the parts costs represent only a portion of the total information desired in an automated system; data on manufacturing technology must also be included because of the relation of ManTech to overall parts costs.

Reliable Data A Must

An automated system which lists parts costs provides a capability to exercise the next important element of the ManTech program—i.e., identity and analysis of the major cost drivers in the production and support of systems/com-

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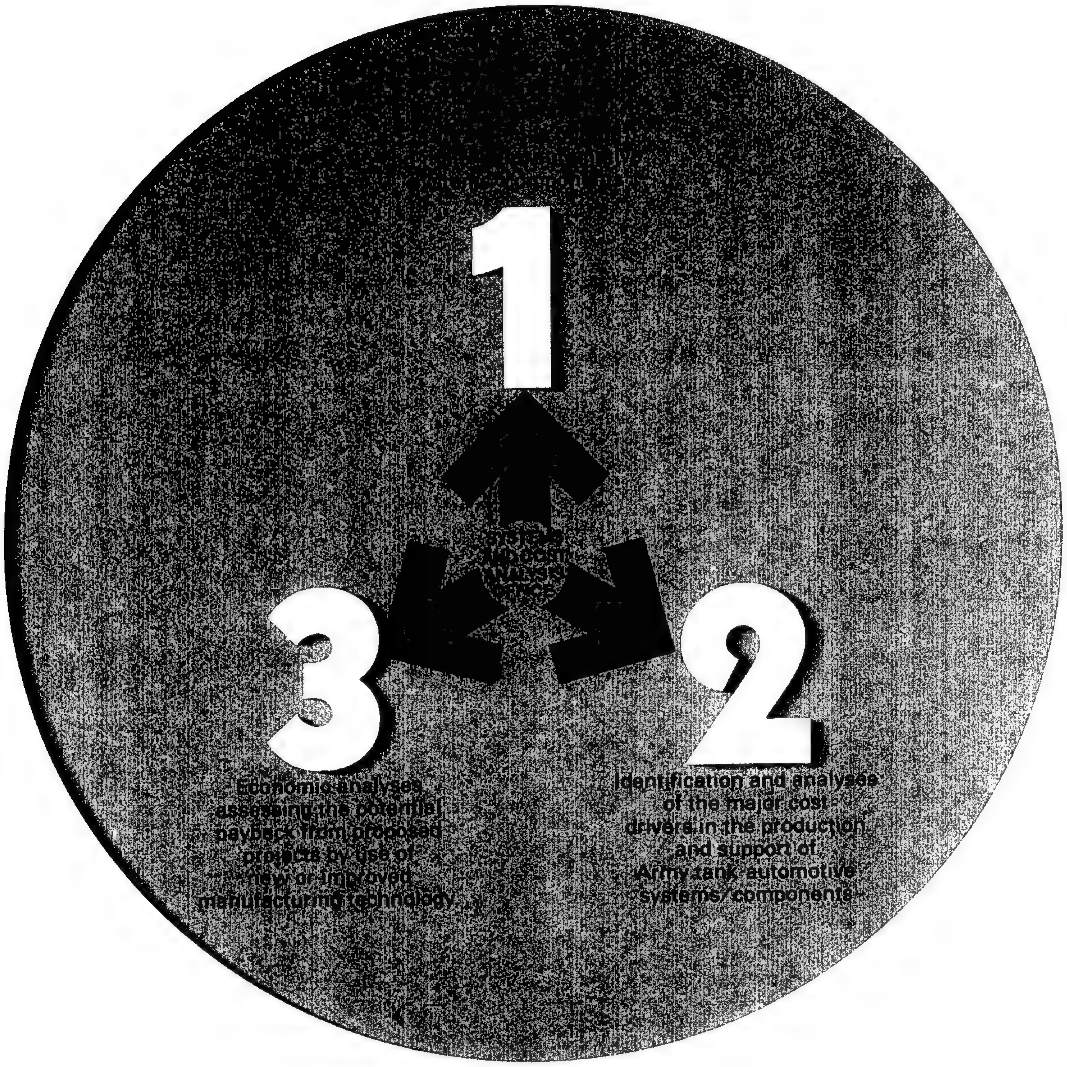


ponents (see (2) above). As noted earlier, an automated information system that breaks down costs of end items is a prime tool for assemblage of costs for analysis. Special computer programs applied to the information system identify the major cost drivers for either a given system/component or the aggregate systems/components. The effectiveness of these analytical procedures depends upon the degree of availability and validity of automated parts cost data.

Computer Displays Ease Task

Currently, production parts cost data for the M60 tank has been automated to a great extent. Similar data is available for the M113A1 armored personnel carrier and several other systems, but automation is needed. The costs, too, of repair parts support for operating systems/components are available, already incorporated into an automated information repository under ALPHA (Army Logistics Program Hardcore Automated). Functional computer routines exist that display this information in varied formats. "Querying" programs easily identify major cost drivers thru use of these various displays.

Costs, Benefits Evaluated

The third major support element of the Cost Analysis Office for the TARADCOM ManTech program provides economic analyses of new or improved manufacturing technologies that are applied to major cost drivers (see (3) above). These economic analyses apply in the vein of AR 1128, analyzing the cost/benefit relationships between prevailing and new or improved manufacturing technology. The analyses require development and/or validation by TARADCOM's Cost Analysis Division.

Upon completion of all three of these functional elements for a given ManTech project, TARADCOM is confident of pursuing the best cost/benefit compromise attainable for any given period, considering the prevailing state of the art.

Brief Status Reports

JOINING OF DISSIMILAR METALS. Production welding procedures are being developed for use of dissimilar armor metals in weld jointed configurations for combat vehicles such as the XM-1. Steel and aluminum armor can be welded together by use of specially developed bimetal transition strips between the aluminum and steel joints. The 1400 F (800 C) difference between the melting points of the two metals creates unique welding problems which are being resolved before fabrication of armor test plates for ballistic testing. Determination of sequence of welding, types of joints and weld passes (beads or weaves), and optimum heat input to control maximum temperature (to avoid deterioration of the interface bond of the transition strips) are now in progress. For additional information, contact Mr. G. Wassel, (313) 573-1354, AUTOVON 273-1354.

IMPROVED SEATING FOR MILITARY VEHICLES. The purpose of this program is to establish manufacturing methods and techniques to be utilized in the fabrication of a new type of military vehicle seat. This is being accomplished by the fabrication of a one piece molded polyurethane skin-polyurethane foam cushion. Final mold designs, fabrication techniques, and quality control parameters were used to produce prototype cushions designed to be more comfortable than the conventional seat and to last the life of the vehicle. Cushions are being tested on vehicles at various TECOM test sites having varied climatic conditions. For information, contact Carter Jackson, Jr., (313) 573-1352 or AUTOVON 273-1352.

FORGING LARGE ARMOR SECTIONS FROM CAST PREFORMS. A method of forging large armor steel sections from cast preforms has been developed which involves a preliminary shaping of the end item by casting and then finish sizing by forging. The feasibility of this method was proven by the preparation of ten full-scale cast and forged M60 tank hull nose sections. Final item preparation and evaluation work was concluded this past year. Results have substantiated the hypothesis that such a manufacturing procedure can offer a cost effective means of producing complex large armor components where sufficient production quantities can realistically amortize initial die costs. In addition, a significant ballistic improvement over casting fabrication is obtained, along with improved item reliability and part to part reproducibility. For additional information, contact Mr. Harry Spiro (313) 573-1389 or AUTOVON 273-1389.

ROTATIONAL MOLDING OF LARGE CAPACITY FUEL TANKS FOR COMBAT VEHICLES. This project was undertaken to develop a process to rotationally mold large nonmetallic fuel tanks for combat vehicles. Weight reductions from 50 to 60 percent are anticipated; however, elimination of corrosion is the greatest benefit expected from this program. Cost effectiveness studies are still being evaluated, and final price comparisons are not available at this time. High density polyethylene is being used, and this material has satisfactorily met all Army environmental requirements. For additional information, contact Mr. Don Matichuk, (313) 573-2084 or AUTOVON 273-2084.

PRODUCTION METHOD FOR HIGH EFFICIENCY JOINING OF ESR ARMOR. This project is aimed at establishing production welding techniques for a steel armor made by a new process known as Electroslag Remelt (ESR). This "clean" armor steel offers a high degree of ballistic protection, but, without high joining efficiencies that can be maintained in a production environment, its application to combat vehicles will be limited. Welding parameters for production will be established for economical and reproducible methods of fabricating ESR armor. Optimum welding procedures have been developed, and welded test plates for ballistic testing at Aberdeen Proving Grounds and a simulated hull have been fabricated using these procedures. The hull is presently undergoing X-ray examination to determine integrity of the weld joints. For additional information, contact Mr. B. Schevo, (313) 573-2467 or AUTOVON 273-2467.

FABRICATION OF ARMORED VEHICLES BY THE ELECTRON BEAM WELDING PROCESS. This project was established to determine the manufacturing procedures required to implement the electron beam welding process

for production of aluminum armored vehicles. This process has the potential of high productivity at reduced cost. The total effort is planned in three phases. The first phase considered welding parameters, joint design, and ballistic evaluations of welded samples. The second phase effort proposed design and fabrication of a structure approximating a full size vehicle. The concluding effort planned the actual fabrication of a large structure simulating a full size vehicle using welding procedures, tooling, and fixtures of prior efforts. The first phase effort is approximately 90% complete. The second and third phase efforts have been combined contractually to design and fabricate tooling and fixtures and ultimately fabricate a hull structure. Completion is expected in June 1978. For additional information, contact Mr. Donald E. Phelps,(313) 573-2433 or AUTOVON 273-2433.

PROCESSING ESR STEEL FOR IMPROVED HOMOGENEOUS ARMOR. Recent R&D efforts have demonstrated that homogeneous wrought steel produced by the electroslag remelting (ESR) process can be fabricated into high hardness steel armor plate possessing optimum metallurgical properties. Superior ballistic performance has already been demonstrated, along with good fabricability, structural integrity, and ballistic damage tolerance. This project will provide for scale-up and the establishment of an industrial base for quantity production of armor to establish parameters, process specifications, and limited simulated service testing. ESR ingots of optimized alloy have been produced in-house at AMMRC, and a heat treatment furnace has been purchased and installed at a contractor's facility. Large plate specimens are presently undergoing heat treatment prior to ballistic testing at Aberdeen Proving Grounds. For additional information, contact Mr. F. Moore, (313) 573-1466 or AUTOVON 273-1466.

EVALUATION OF WELD PENETRATION CONTROL EQUIPMENT AND APPLICATION TO THE WELDING OF ARMOR. This project seeks to develop and evaluate weld control equipment and to assemble it into a system for controlling welds in armor. The system will be evaluated against weldments of armor alloys of varying compositions and plate thicknesses. Such a system will minimize crack-like flaws detrimental to ballistic and mechanical properties of armor by insuring optimum penetration of weldments during joining operations, thus providing significant cost savings by reducing over welding or repair welding. For additional information, contact Mr. B. Schevo, (313) 573-2467 or AUTOVON 273-2467.

ISOTHERMAL HEAT TREATMENT FOR HIGH STRENGTH DUCTILE IRON CASTINGS. The purpose of this project is to establish production processing technology for isothermal heat treatment of ductile iron castings and to produce components with good low temperature ductility, an essential property of vehicular components used in the total temperature environment in which these vehicles operate. Cast irons, as presently procured, lack sufficient ductility to be used in all temperatures of the military environment. Cast steels, on the other hand, lacking the better castability of iron, cannot be cast to the desired low dimensional tolerances, thus requiring more machining. Prototype track shoes, track guides, and road arms for the M113 are presently undergoing service testing at Yuma Proving Grounds and the Cold Regions Test Center in Alaska. For additional information, contact Mr. G. B. Singh, (313) 573-2065 or AUTOVON 273-2065.

AUTOMATED GAS METAL ARC WELDING OF STEEL HULL STRUCTURES IN MORE THAN ONE AXIS. This project establishes automated production welding processes to fabricate combat vehicles with improved reliability and maintenance dependability features and to minimize reliance on human factors. It supports welded steel plate armor vehicles, such as the XM1. Automated welding machinery, manufactured to meet military requirements, has been procured, installed and calibrated. Test specimens of welded armor plate have been fabricated using processes developed under this project and ballistically tested in March 1977 at Aberdeen Proving Grounds. Successful completion of this project will lead into a similar one for welding of aluminum hull structures of such vehicles as the M113, MICV, and Commando. For additional information, contact Mr. E. Balla, (313) 573-2467 or AUTOVON 273-2467.

Near Net Shapes Mean Less Chips

Helicopter Manufacturing Technology

Part 2: Drive System and Turbine Engine Technology

Programs now under way to improve the manufacturing technology of helicopter drive systems and turbine engines will meet the need for lower manufacturing costs outlined in Part I of this series, and at the same time they will provide improved reliability and longer service life for important components.

Emphasis in these programs is on manufacturing improvements and component producibility.

- Manufacturing improvements are directed toward producing forged and cast components near their final shape in order to reduce machining time and costs.
- Component producibility is being achieved by developing the capability to process advanced materials into improved parts.

Significant cost reductions have resulted from these programs.

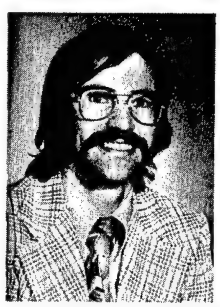
New Processes/Materials for Drive Systems

Helicopter drive systems (as typified in Figure 1) contain a number of transmissions and drive shafts to transmit power from the engines to the main rotor, the tail rotor, and accessories. Also included in these drive systems is an auxiliary power unit (APU). This unit drives accessories while the aircraft is on the ground and starts the main engines.

Transmission housings usually are made of cast magnesium with steel bearing liners. The transmissions contain a number of spur, helical, and bevel gears as well as a variety of bearing assemblies, sumps, oil coolers and seals. The gears usually are machined from forgings of gear steel. Most transmissions are filled with oil, although some of the more recent gearboxes are lubricated with grease. Shafts mostly are made from aluminum, with steel interconnections. The auxiliary power unit contains forged and machined centrifugal compressor and radial turbine wheels. Current cost reduction projects are reviewing all of these parts for more efficient means of fabrication.

Forged Gears Less Costly, Tougher

Precision forging of transmission gears will bring a 50 percent reduction in material costs and 40 percent decrease in manufacturing man-hours. Present helicopter transmission gears are machined from forgings, case hardened, and heat treated. The current manufacturing



ROGER L. SPANGENBERG is an honor graduate in Aerospace Engineering of the University of Maryland and holds a Master's Degree in Industrial Engineering from Texas A&M University. He is also a graduate of the U.S. Army Engineering Intern Training Center in Product/Production Design Engineering. Mr. Spangenberg has spent five years with the Department of the Army in both technical and management capacities. At the U.S. Army Aviation Systems Command, he was project engineer for the development of advanced manufacturing technology for production of engine and airframe components used in Army helicopters. While at AVSCOM he also served as the Command's Computer Aided Manufacturing coordinator. In his present position at the U.S. Army Tank Automotive Command, Mr. Spangenberg is responsible for management of planning and programming for the XM-1 Tank Development. He is a member of the Tau Beta Pi, Sigma Gamma Tau, and Alpha Pi Mu honor fraternities, and he is a member of the AIAA and SAMPE technical societies.

Editor's note: This series of articles was written by Mr. Spangenberg while he was with the production Technology Branch at AVSCOM. Since completing the articles, he has assumed a new position with the U.S. Army Tank Automotive Research and Development Command. Readers wishing to acquire more information about AVSCOM's helicopter manufacturing technology program may contact Mr. Gerald Gorline or Mr. John Stanfield at (314) 268-6476 or AUTOVON 698-6476.

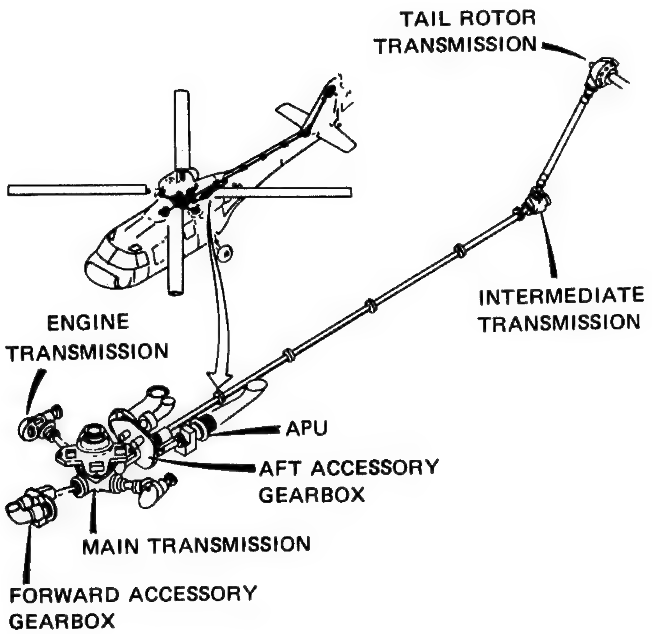


FIGURE 1

technology effort involving TRW, Litton, and Boeing-Vertol is designed to eliminate the extensive chip removal and tooth cutting operations involved. A spiral bevel gear is forged with integral teeth by a mechanical press, requiring only finish grinding. Figure 2 shows the sequence of operations used in the precision forging process, development of which is nearly complete.

In addition to saving costs,gear quality is improved. The machining required for cutting the gear teeth in a conventional forging results in residual metallurgical stresses. Precision forging, on the other hand, improves the metallurgical grain both in the whole forging and also in the individual gear teeth, providing longer gear life.

After completion of the project, testing will continue for several years to generate the confidence necessary for use of these critical components. This near net shape forging process will be put into production after these tests achieve their purpose.

Cast Wheels Save $1000 Each

Solar—in cooperation with its titanium casting suppliers—is developing a casting technique for compressor wheels in its Titan auxiliary power unit that will result in a titanium wheel that is cast to near its final shape. Although foundries are now producing castings in a variety of complex shapes, their application has been limited to lower speed, noncritical rotors or static components. Application to higher speed compressor rotors, such as in the Titan, has been hampered by the presence of casting defects resulting from contamination and shrinkage during solidification. Recent refinements of titanium casting methods to minimize these problems have brought about the application of these castings to critical components.

Army helicopters such as the CH-47 and CH-54 have used the Solar Titan auxiliary power unit for several years. Improvements in this unit have included incorporation of a titanium centrifugal compressor wheel, which has allowed the compressor to meet increased bleed air and horsepower requirements within the same envelope as in previous versions, which utilized steel or aluminum wheels. However, the titanium wheels cost considerably more, because forged wheels were machined by a combination of single point cutting tools and electrochemical machining. This method not only required a great deal of labor, but at prevalent titanium prices produced very expensive chips.

The program under way will develop these new production techniques for casting auxiliary power unit compressor wheels and will follow up with extensive tests to qualify the components for Army use. At the conclusion

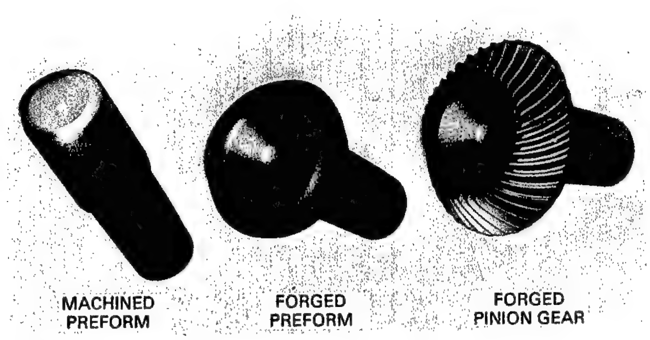
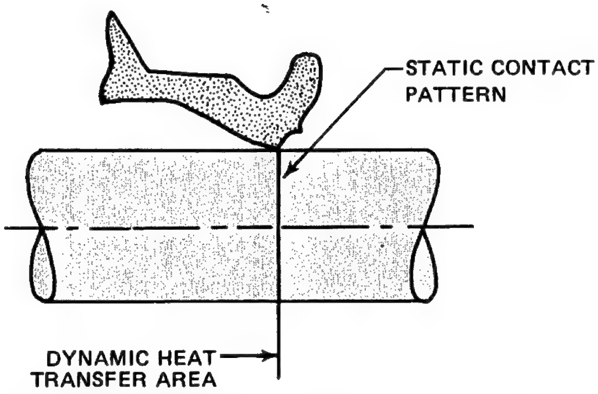


FIGURE 2



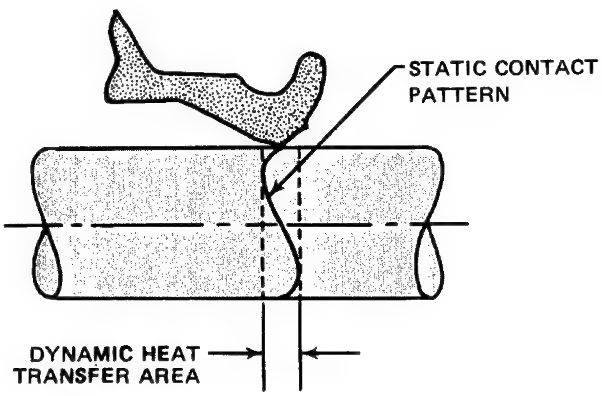


FIGURE 3

of the project, the casting process is expected to be used in all of the auxiliary power units for Army's new utility transport and attack helicopters, producing cost savings of $1000 per compressor wheel.

VASCO X-2 Extends Gear Life

VASCO X-2 gears will be used for transmissions in the Boeing-Vertol CH-47 modernization aircraft. The greater load carrying and longer life characteristics of the improved gear materials will result in significant reliability and performance improvements, as well as gear life increases to nearly 50 percent.

The increasing speed and power levels of the new generation of helicopter transmissions requires that gears and bearings made of conventional materials such as AISI 9310 become larger and heavier. Consequently, the application of materials like VASCO X-2—with superior high temperature and high strength characteristics—has been undertaken. However, processing that will make the materials usable in large scale production has been lacking.

The Aviation Readiness and Development Command, the Army Materials and Mechanics Research Center, International Harvester, and Boeing-Vertol all have begun developing heat treatment processes for gears made of VASCO X-2 high hot hardness steel. To date, these efforts have indicated superior high strength, high temperature characteristics of the VASCO X-2 alloy; the material is expected to maintain strength to 1000 F, whereas materials such as 9310 normally have strength retention only to 350 F. VASCO X-2 will also carry a 20 percent greater load than 9310.

Plans call for finishing the gears by ausrolling,which will reduce the amount of costly grinding required to meet tolerances and will produce gears of the desired shape. When compared with conventional gears, VASCO X-2 gears will have lower residual stress and improved surface compositions.

Improved Seals From New Materials

A key maintenance problem in helicopter transmissions is the wearing out of seals at various points, with the subsequent loss of transmission fluid. Figure 3 shows a new radial lip seal design for the input quill assembly on the UH-1 main transmission. This seal was produced from the advanced elastomeric compounds Viton and Polyphosphazene during a recent manufacturing technology project. The compounds offer increased resistance to oils, which improves both the quality and the life of transmission seals made from them.

The current lip seal is molded from a fluoroelastomeric compound and trimmed to size. Control of the seal to seal concentricity and the uniformity of the seal cross section is difficult using the trimmed design. The new design incorporates a fully molded lip configuration that overcomes these problems, providing the increased seal contact pattern indicated in Figure 3.

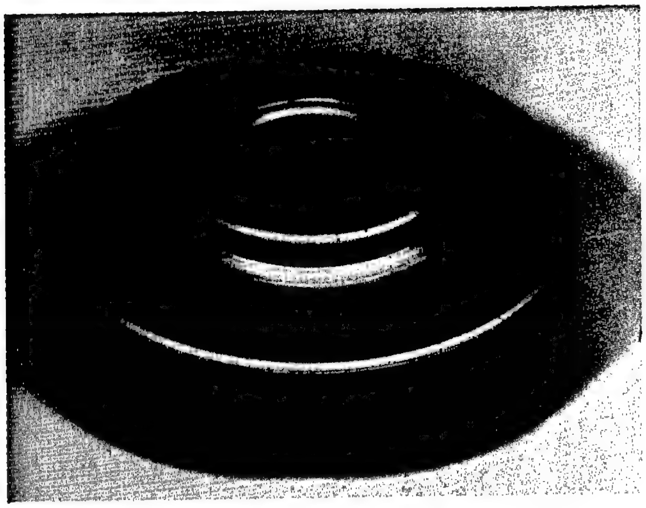


FIGURE 4

This manufacturing technology project has provided the capability to produce transmission seals that prevent leakage for long periods of time. The seals produced under this program are now undergoing flight testing. At the conclusion of this testing, the new seals will be available for replacement during maintenance. Manufacturers already have specified these new seals for use in future helicopters.

Process Development Reduces Turbine Engine Costs

Turbine engines supply the power not only for current Army helicopters but they also will be used to power the next generation of helicopters as well. Both forged and machined centrifugal compressor impellers and axial compressor stages with forged and machined blades are used; all are made of either stainless steel or titanium. Axial gas generator and power turbine stages utilize forged and machined disks and cast blading made primarily of nickel based superalloys. Complex brazed sheet metal structures are used for such components as diffusers and turbine nozzle assemblies.

The latest entry into the Army inventory of turbine engines is the General Electric T-700. This engine generates over 1500 horsepower and will be used to power both the new attack and utility helicopters. The T-700 offers improved reliability and maintainability and increased performance. It has been the subject of several recent manufacturing technology programs that promise significant cost savings.

Improved HIP for Disks

Current costs of T-700 stage 1 and Stage 2 turbine disks are high due to the cost of the high temperature RENE 95

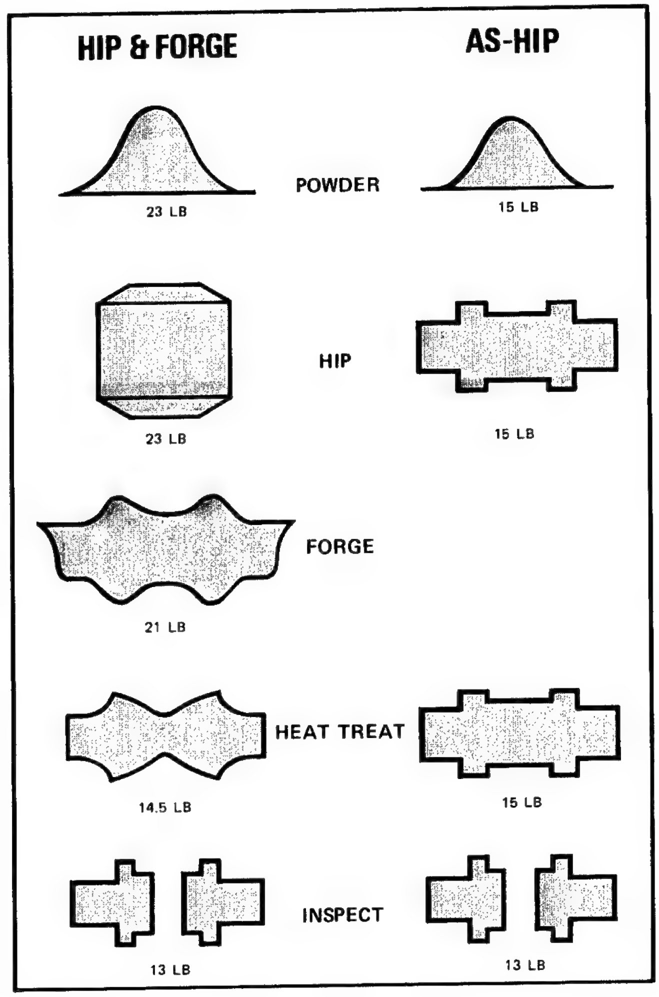


FIGURE 5

alloy used and its resistance to forging. An improved powder metallurgy process that eliminates the forging operations offers cost savings of nearly $1000 per engine. At present, RENE 95 powder is pressed into compacts. These compacts are subsequently forged and then machined to final configuration. This hot isostatic pressing (HIP) process, which replaced conventional forgings, resulted from combined efforts of General Electric and a number of powder compact and forging vendors.

The recent manufacturing technology effort was aimed at eliminating the costly forging operation through the development of the "as-HIP" method to press RENE 95 powder directly to the shape depicted in Figure 4. This disk requires only machining to final shape, heat treatment, and inspection. Results indicate that mechanical properties required of a RENE 95 forging can be achieved without the forging operation. This is because the powder metallurgy process tends to eliminate some of the usual reasons for forging, such as grain refinement and control of flow lines and overall shape.

Figure 5 compares the present HIP/forge process with the new "as-HIP" process. Cost savings are due primarily to

FIGURE 6

the elimination of the forging operation, but there is also a savings in material. The "as-HIP" turbine disks are currently undergoing tests prior to their incorporation into the T-700 production program.

Cast Compressor Cases Save Material And Labor

Results of a current manufacturing technology program indicate that a new method of casting T-700 compressor cases will save about $650 per engine over present forging methods. The compressor case shown in Figure 6 is a titanium forging that is turned on the inner diameters. It requires several slow, costly milling operations on its outside diameters, which have a number of integral flanges and connecting points.

A program is now under way with the Air Mobility Research and Development Laboratory (AMRDL) and General Electric and its vendors to develop and demonstrate a precision casting technique for producing the case. Precision casting will provide cases with external features cast to size and with the interior closer to finished size.

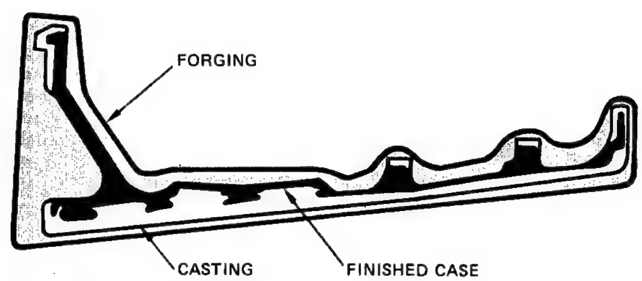


FIGURE 7

Figure 7 shows a cross section of the case, indicating the machining required after both conventional forging and precision casting. The base weight of the forging is 50 pounds for a finished case weighing only 8.5 pounds. Nearly 42 pounds of titanium chips end up on the floor. The precision casting will weigh only 15.5 pounds and the subsequent machining operations are relatively simple. Because of the cylindrical shape of the casing, centrifugal casting is one method being investigated. This dynamic casting technique will produce high quality castings and should eliminate postcasting HIP procedures to seal internal voids, thus reducing production costs.

Improved Casting Process For Turbine Blades

Figure 8 shows the configuration of a T-700 turbine blade that was directly cast with integral cooling passages under a manufacturing technology project with AMRDL and General Electric. Savings for this blade are estimated at $200 per turbine stage; fatigue characteristics of the blade also are improved significantly.

Previously, it was necessary to modify blade designs so that only part of the cooling passages were directly cast; subsequent electrostream drilling of trailing edge holes was required to complete the passages.

As shown in Figure 8, a series of bent quartz coring rods are used to cast the cooling passages. The rods were previously assembled in a bundle and cemented into a ceramic core (which was also used to form the tip plenum) prior to wax injection. Location of radial holes near the thin trailing edge was limited by the inability to attach rods to the thick ceramic core in that area. As a result, axial trailing edge holes were used to provide cooling. In the new design, the quartz rods are precisely placed directly into

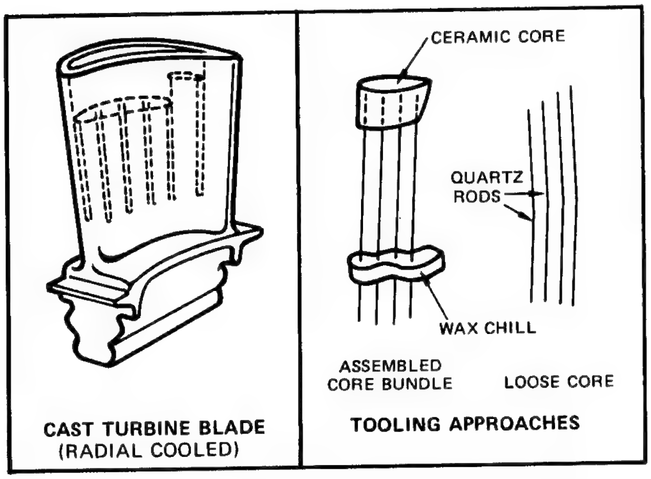


FIGURE 8

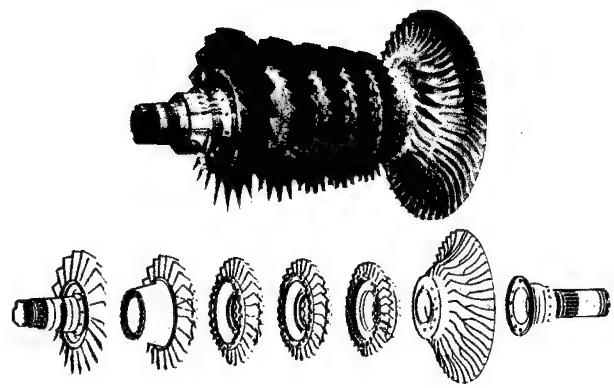


FIGURE 9

the wax pattern and radial holes are located closer to the trailing edge to provide the necessary cooling.

The new design will be less expensive to produce. The bundled core required higher material costs and high labor costs for hand assembly. In addition, there was poorer tolerance control and also considerable breakage during injection. The effective yield of castings, now 20–25 percent, is expected to increase to 80–85 percent; the wall thicknesses, which previously were as little as 0.006 inch, will now be more than 0.015 inch; no trailing edge drilling will be required, and a simple electrical discharge machining operation will be used to form the tip plenum.

At the conclusion of the Manufacturing Technology project, the improved process will be implemented in the production of T-700 engines.

NC Milling Cuts Costs of Blisks

Results from a current Manufacturing Technology program indicate that automated machining of "blisks" for T-700 rotor assemblies will halve labor costs. Similar to current helicopter turbine engines, the T-700 contains a compressor rotor assembly consisting of five axial rotors and a centrifugal impeller (Figure 9). However, axial rotors for the current turboshaft engines have conventionally been designed with disks which are slotted to engage the "dove tail" root ends on individual blades. The T-700 has been designed with integral rotors called blisks (the term blisk refers to the concept of combining the blades and disk into a single unit).

The current project with General Electric seeks to establish a more economical manufacturing process for the blisks. Prototype blisks presently are fabricated by rough cutting the forgings using pantograph techniques and subsequently hand finishing the multibladed components. This hand production method is both time consuming and costly. The techniques and facilities used are adequate for fabricating a limited number of prototypes, but not so for the full scale production planned for the future.

In the Manufacturing Technology project, GE is investigating automated techniques to develop full scale production capability. The particular process being developed involves rough cutting the forgings on four spindles of a multiaxis, numerically controlled mill and then finishing the thin blades with abrasive flow. When fully developed, the process will mass produce the blisks in only half the man-hours needed for hand production.

Part I of this three part series, which appeared in Vol. 2, No. 1, of the Army **ManTech Journal**, highlighted manufacturing improvements and cost savings in helicopter airframes and rotor systems. Part III, to appear in Vol. 2, No. 3, will review projected manufacturing improvements over the next several years.

Revolutionary System Less Costly

Automated Pumping Loads Explosives

WAHLING H. NG is project engineer for the U.S. Army's Munition Production Base Modernization and Expansion Program, performing a wide variety of engineering duties required in the development of advanced munition process technology. In 1976, he was presented with a Picatinny Arsenal Research and Engineering Award for contributions in the Army's Modernization Program. Mr. Ng holds a Bachelor of Chemical Engineering degree from Indiana Institute of Technology and a Master of Science degree in Chemical Engineering from New York University.

Major caliber shell loading on the modernized 105-mm line at Lone Star Ammunition Plant, Texarkana, Texas will be based on a new system which continuously pumps molten TNT and molten Composition B.* This is a dramatic departure from the old batch process in use at loading plants and represents another example of how the Army is seeking new technology to replace obsolete methods in its munitions production mission.

Manufacturing methods for melting and pouring TNT based explosives in loading operations are severely limited by techniques which are primitive by today's standards of technological sophistication. Little change has been effected since World War II in the melt-pour process. Some improvements have been made, but the method—which consists of a batch process using gravity feed from multistory buildings—still persists. In this process, solid explosive is introduced gradually into a large heated kettle where melting is accomplished. The molten explosive is then allowed to flow by gravity to a loading station where it is poured and cast into shell. The present melt-pour operations are outdated and primarily accomplished by hand. Operators are exposed to very hazardous operations as the present equipment requires large quantities of in-process explosives.

New Method Sought

As part of the Army Production Base Modernization and Expansion Program, Picatinny Arsenal investigated processes and techniques for the melt loading of high explosives. Major goals were reduction of hazards, reduction of quantity of in-process explosives, increased production capability, reduced cost, improved product, and reduction in explosive allowance per bay. The initial studies indicated that a continous, automated melt-pour process could achieve these goals and would also lend itself to a computer controlled, remotely monitored, fully instrumented system. The key to the operation of this system was the development of a means for transporting molten explosives through the process lines from melter to pouring unit.

The work described in this article covers the investigation, modification, evaluation, and application of pumps to the task of explosives prime mover. Pumps of the diaphragm type or Peristaltic type were considered to be suitable for investigation, since they are capable of forcing the molten explosives through a pipe without the applica-

*Composition B is a special type of high explosive composed of 40% TNT (Trinitrotoluene, $C_7H_5N_3O_6$) and 60% RDX (Cyclonite, $C_3H_6N_6O_6$) with a small amount of wax additional.

tion of dangerous sudden localized high pressures or friction forces. It is very important that the flexible parts of these pumps, viz, tubing and diaphragms, in contact with the process product be compatible with the molten explosives and possess adequate operating life at elevated temperatures ranging from 180 to 250 F. Viton, silicone rubber, and Teflon are examples of compatible materials for these flexible parts.

One type of industrial pump especially designed for difficult chemical and food applications is the Peristaltic pump. This type of pump contains no valves or seals and is engineered so that the fluid does not contact the working parts of the pump. An extruded or molded elastomer tubing is squeezed by rollers, which push the fluid through. By using different tubing materials, virtually any type of compatible liquid or slurry can be pumped with this Peristaltic device.

Another type of commercial pump is one of the diaphragm type known commercially as Pulsafeeder Metering Pump with remote Hydratube head. The unique feature of this pump, which sets it apart from other diaphragm pumps, is the remote Hydratube head which can handle higher viscosities, and heavier slurries, which can transport molten product in a remote tube/check valve assembly. The Hydratube operates within a metallic housing filled with an intermediate hydraulic fluid that is selected to be compatible with the product. This completely eliminates the potential hazard of explosive particles settling into crevices in the metal head and gear box parts. For these reasons, this pump design was reviewed by the Safety Office at Picatinny Arsenal and found to be safe for the pumping of molten explosives.

Peristaltic Pump Features No Contact

The Peristaltic pump with air motor utilizes an elastomeric tube as the pumping element. The fluid being pumped is forced through the tube by the squeezing action of rollers which press the tube against the pump housing. This seals the tube into an input section behind the moving roller and an output section ahead of it. The roller forces fluid ahead of it by the compressive pressure exerted on the tube and creates a partial vacuum behind it which draws fluid into the low pressure area. As the rollers revolve with each turn of the pump, a steady flow is developed and higher vacuum is developed. Rate of flow is dependent upon pump speed. The ability to develop a vacuum behind the moving roller is dependent on the ability of the tube to return to its original shape after compression. No moving parts contact the fluid other than the compression and expansion of the tubing, thus making it an attractive device for handling sensitive materials.

Peristaltic Pump Use Limited

A series of tests were performed using inert fluids to simulate the explosive. Initial runs were performed with hydrostearic acid (octadecanoic acid) at a temperature of 200 F as a simulant for TNT. Pumping and recycling were accomplished in a system as shown in Figure 1.

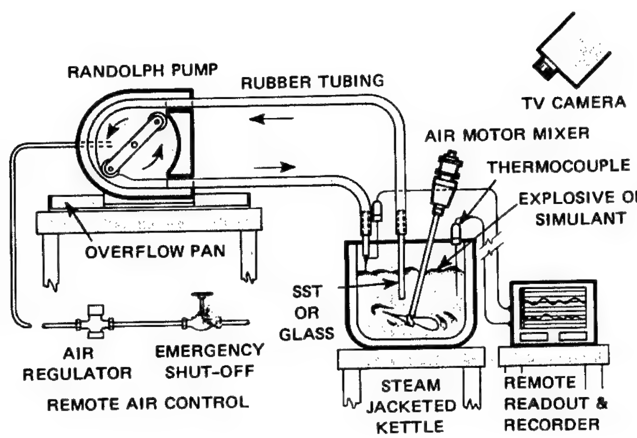


FIGURE 1

A composition consisting of approximately 50/50 hydrostearic acid/gypsum powder was used to simulate Composition B. This material froze in the tube when pumped at a temperature of 200 F. Application of steam to the elastomeric tubing remelted the simulant so pumping could be resumed. Using the same test setup, molten TNT was introduced into the system and pumped at a temperature of 200 F with various tubing materials, most of which ruptured. Tube rupture may have been caused by a combination of high temperature and mechanical stress. Erosion by the molten TNT was also a contributory factor. These experiments indicated silicone rubber to be the best choice for pumping molten TNT.

The same test setup with silicone rubber tubing was used for pumping molten Composition B at 210 F. It was necessary to pump steam heated water through the tubing for at least five minutes prior to pumping molten Composition B in order to preheat the tubing. If this was not done, solidification of the Composition B occurred inside the tubing on both sides of the pump because of the cooling

effect of ambient air. Results indicate this pump to be suitable only for pumping molten TNT or Composition B for runs of relatively short duration and for short pumping distances. Low line pressure prevents long distance pumping operations from being feasible.

Pulsafeeder Operates Remote

Metering pumps such as the Pulsafeeder (Lapp) were originally developed for the treatment of water for purification and softening, for the injection of additives into petroleum products, and for adding chemicals to paper pulp. These were the first continuous processes that required proportionate feeding of chemicals. The concept for modernizing the Army's melt-pour process required the use of such a pumping machine; but it needed to be located at a considerable distance from the melter. The temperature of the molten explosive must be at least 180 F and the pumping system must bring no materials incompatible with the explosive in contact with it, nor can it impose intolerable stress upon the explosive. These requirements brought about important modifications to the standard Pulsafeeder and necessitated the design and development of new and unique components to cope with them. A variety of compatible valve and reagent head assemblies for operation at high temperature remote from the gear box had to be developed.

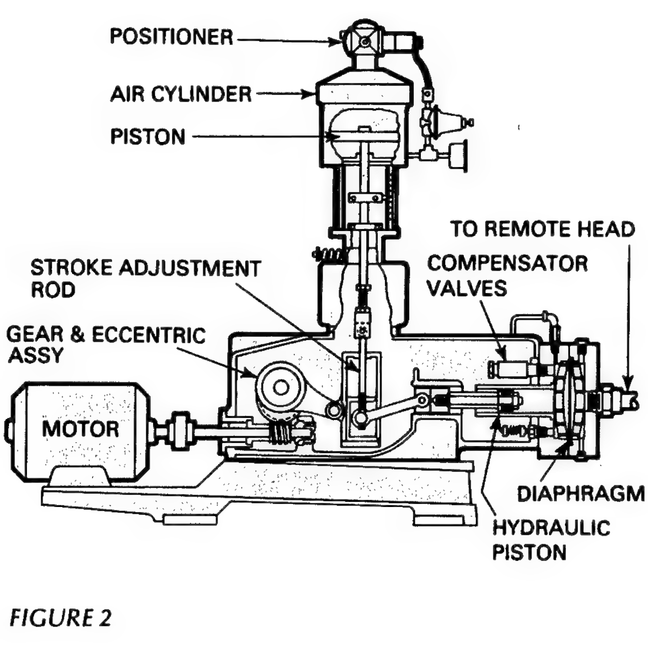


FIGURE 2

The pumping system developed consists of a hydraulic diaphragm pump with a transfer head connected to a remote reagent head as shown in Figure 2. Hydraulic fluid provides the medium for transfer of pumping action to the remote head. This system isolates the molten explosive from the mechanical parts of the pump and requires failure in both heads for explosive to reach the pump. A variety of transfer fluids may be used within the hydraulic transfer system to meet a broad range of temperature or compatibility requirements.

The principle of operation is that reciprocating action of a piston within a cylinder displaces a measured amount of hydraulic oil. This, in turn, moves a flat diaphragm supported by a disc plate with small orifices within a contoured chamber. Compensator valves automatically maintain the hydraulic system balance to ensure metering accuracy. A remote Hydratube head is the reagent head used in this system. The Hydratube is a flexible cylinder that confines the pumped liquid internally, isolating it from any contact with the hydraulic system. The Hydratube responds exactly to the action of the primary flat diaphragm through the medium of an inert intermediate fluid selected to be compatible with both molten explosive and hydraulic fluid. The Hydratube construction with straight through flow path can handle higher viscosity materials and slurries at greater efficiencies.

Temperature Control Mandatory

In order to maintain a desirable temperature range throughout the whole process system, a stainless steel jacketed piping arrangement heated with steam was used for system setup. A specially designed remote head heater containing fire resistant fluid was used to maintain temperature of the explosive inside the remote Hydratube heads. Various types of explosive melters have been used for the Pulsafeeder pumping operation depending on individual special requirements. Compatibility studies were performed in advance in order to choose the right type of materials for pump parts. It was necessary to modify the check valve assemblies with a rigid steel support to eliminate deformation caused by prolonged exposure to high temperature. This caused a decrease in suction and constricted check valve passage area which in turn reduced flow rate. Preliminary pumping tests were made with glycerine at various viscosities (15-1,000 cps)—depending on temperature conditions—to check out the system prior to runs with explosives.

Duplexing Best Solution

Two duplex Pulsafeeder metering pumps (Lapp) were used in both component testing and pilot plant systems. This assembly consists of two pump gear boxes and diaphragms driven by an air motor, along with two remote Hydratube heads. The stroke length of each gear box is monitored by an auto pneumatic control; output is directly proportional to the instrument air signal. The pump gear boxes were 180 degrees out of phase.

Results of experiments indicated that shutdown without purge of the remote head Hydratubes for more than one-half hour induces breakage of the Hydratube upon restart when pumping molten Composition B (settling of the RDX ingredient of Composition B appeared to be the cause), but the failure of the remote Hydratube head did not constitute a hazard during pumping of molten explosives.

The Duplex Pulsafeeder metering pump was further proven suitable for a complete recycling system including Porcupine melter unit, rotoclone, diaphragm process valves and a 50 foot recycling loop of steam jacketed piping. Both molten TNT and molten Composition B were successfully pumped and recycled. Molten Composition B was also pumped at various flow rates in a modified Duplex pumping system to provide a 20 foot vertical loop as well as a 40 foot vertical loop. Various shutdown periods were utilized to evaluate the durability of the remote Hydratube pumping systems.

Continuous Flow Test Successful

Continuous melting and pumping of molten Composition B was successfully demonstrated through a complete pilot plant system (Figure 3), including conveyor, weigh feeder, preheater, Porcupine melter unit, duplex Pulsafeeder metering pump, and 120 feet of jacketed process line with various diaphragm valves, static mixers, instrumentation flanges, and detonation traps at rates up to 1100 lb/hr. Recycling, pumping from building to building, various flow rates, purge, shutdown, remote control, instrumentation and monitoring were all successfully performed.

Most of the explosive pumping tests conducted utilize stainless steel ball/TFE seat check valve assembly and silicone rubber Hydratubes in the remote head system. The silicone rubber Hydratubes performed satisfactorily. However, a special TFE diaphragm remote head has been developed as a replacement for the Hydratube remote head, with the objective of improving its service life.

The objective of these tests was not only to prove the functional operation of the Duplex Pulsafeeder but also to demonstrate smooth system control of the continuous process equipment with various flow rates for the melting and subsequent pumping of molten explosive. A process design of production plant scale of the continuous melt-pour system has been generated, based on pilot plant testing data. This system has been incorporated in the modernization plan for the 105 mm line at Lone Star Army Ammunition Plant.

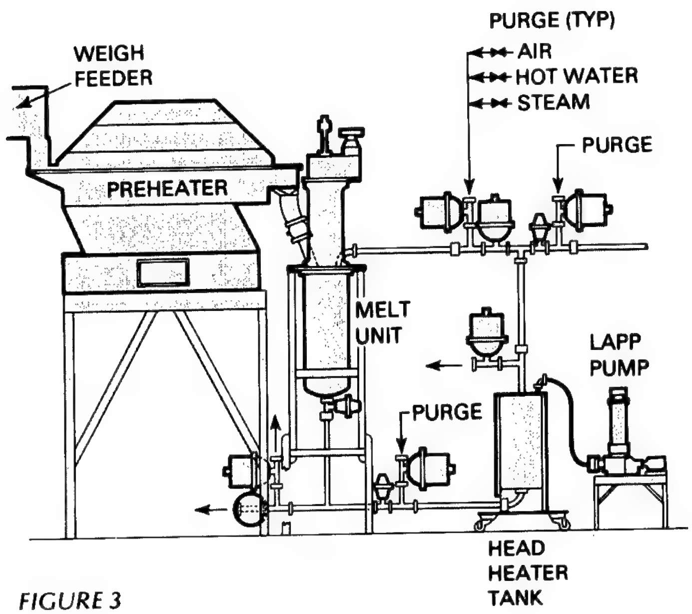


FIGURE 3

Major Benefits Accrue

Several major benefits are derived from this new technology:

- Desired levels of safety for personnel are reached by reducing quantities of in-process explosives
- Lower manufacturing costs are realized by introducing automation and therefore reducing manpower requirements
- Quality of end products is improved through better control of process variables.

Application of this new process is scheduled for implementation into the Army's production plants across the country. As an example, the modernized line at Lone Star is scheduled for completion in 1979. The amount of explosives in the melt-pour process at a given time will be reduced from 15,000 pounds to 2,500 pounds. The number of rejects will be reduced from approximately 300 per shift to 12 per shift. An annual savings of approximately $1 million in a mobilization situation can be realized (based on 907,000 units/month on a 120 hour/week basis).

Ultrasonics Makes It Possible

Milling & Measuring At The Same Time

Close tolerance milling of large, weight critical parts generally leaves an operator in a quandary. He can easily cut too much or too little and be in trouble either way. Operators tend to cut on the high side of the tolerance band, leaving extra material; this avoids the risk of expensive rejections for overthinning, but it also adds weight—at best, an expensive luxury.

The rapid development of numerically controlled milling machines has eased the operators' dilemma, but not solved it. Extensive measurement before the final cut, generally with a hand held ultrasonic instrument, also helps. But this operation costs plenty and still leaves the operator with a tendency to work on the high side on that final cut.

Solution Provided

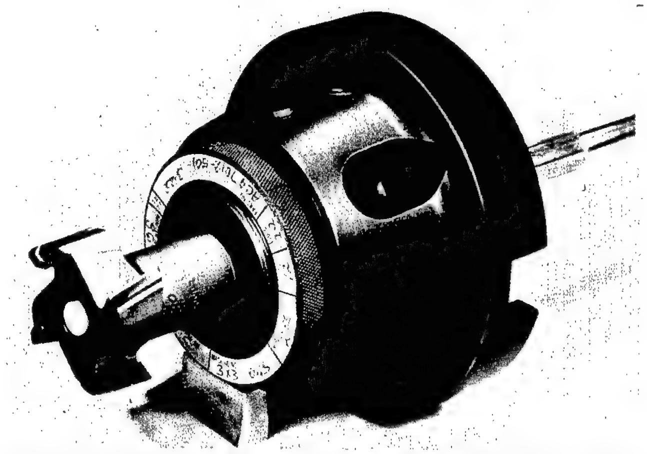
Now, General Dynamics appears to have a solution to the problem—one that promises large savings in both inspection and rework time, as well as material. NC milling machine operators at General Dynamics Convair Division are machining large, close tolerance parts to the low side of the tolerance band without fear of overthinning. And they are saving up to 14 hours per panel in inspection time. How?

A precision ultrasonic system continuously measures and displays part thickness while machining is in progress. At the same time, this instrument monitors the tolerance band and detects out of tolerance dimensions as they start to form. Thus, the operator can correct any out of tolerance condition before it actually occurs. Since inspection is an in-process operation, inspection time is nil.

CHARLES L. HOLLAND is Senior Manufacturing Development Engineer at the Convair Division of General Dynamics in San Diego, California and is Program Manager there for advanced technology research projects. Since receiving his engineering training at Central Missouri University and the University of California, he has spent 35 years in aircraft and missile engineering and manufacturing. He was a member of the original Terrier missile development team and performed extensive engineering and flight support work on the Atlas and Centaur space shots. Mr. Holland holds six patents related to fastening, structures, and ultrasonic measurement systems. He is a senior member of the Society of Manufacturing Engineers and is a Certified Manufacturing Engineer and Registered Professional Engineer in the State of California.

System Installation Simple

In just a few hours, the system can be fitted to any milling machine that has a drawbar type of hollow spindle. Extensive development tests have proven the instrument to be accurate and repeatable. All of which should make the concept extremely attractive to those faced with large scale, close tolerance milling operations.

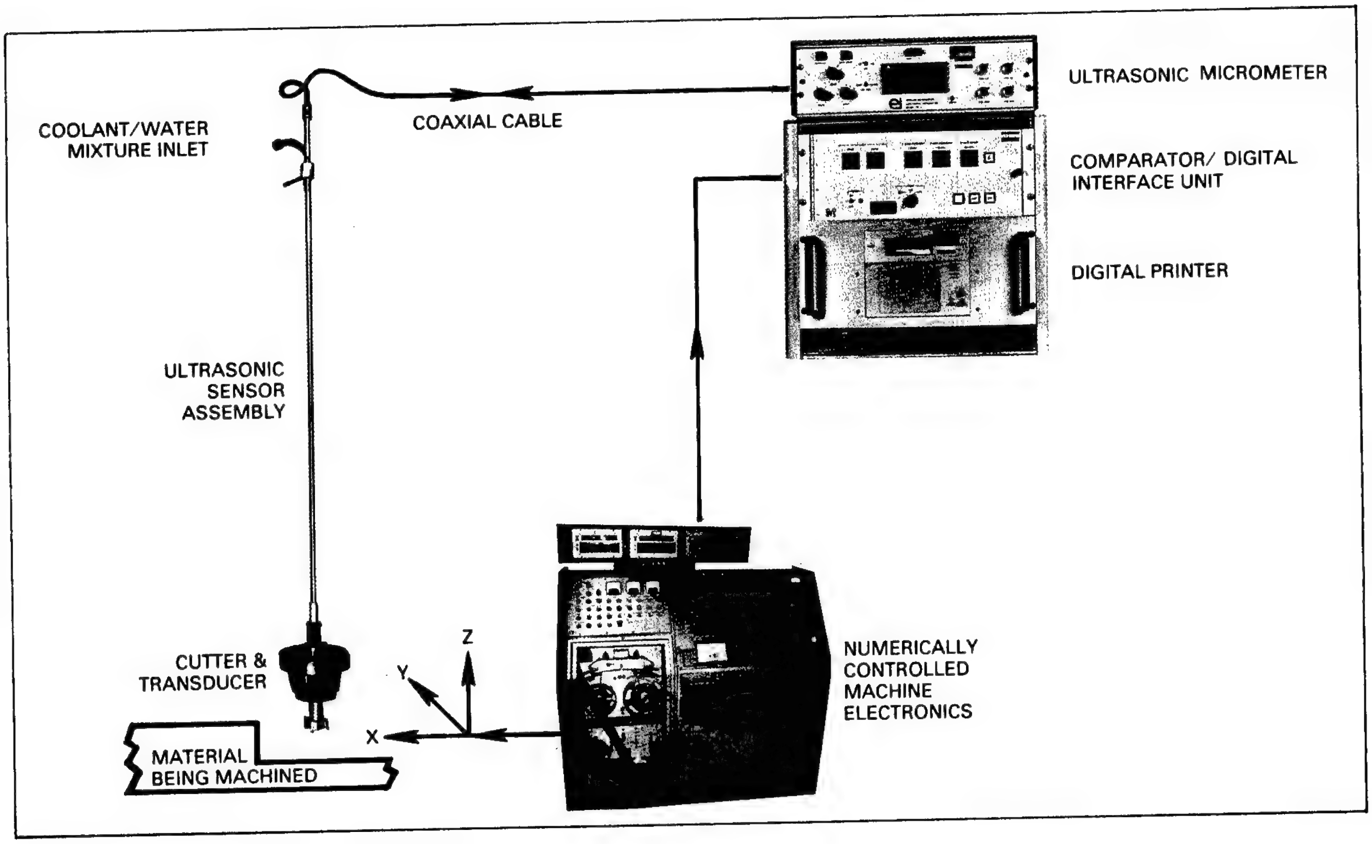


Miniature ultrasonic transducer mounted in milling cutter senses material thickness.

The ultrasonic measuring system was developed for use in milling Space Shuttle skins as large as 7 by 23 feet. These skins are machined from 3 inch thick aluminum billets valued at $6,000 each. The final skins are only 0.050 inch thick with 2-1/2 inch upstanding ribs. The costliness of mistakes and need to maintain close tolerances is obvious.

Blind Side Now Visible

In milling billets of this size, a considerable amount of built-in stress is relieved during machining. As a result, the billet tends to warp and form gaps between the skin and the machine bed, in spite of the fact that the part is held down by clamps and a vacuum chuck. Since the cutter merely follows a programmed path across the workpiece, the operator normally is unaware of the thin spots that this warpage creates. The in-process ultrasonic measurement system now gives the operator blind side visibility. He can machine to the low side of a tolerance band and react in response to any condition which tends to produce overthinning.



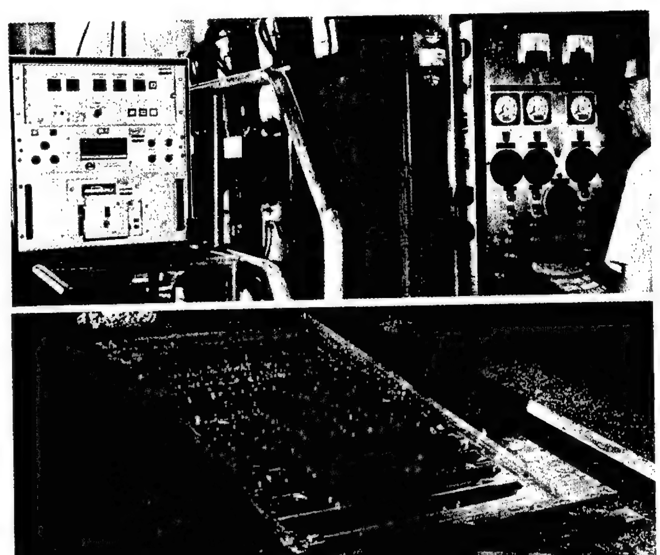
How It Works

The system uses a miniature ultrasonic transducer mounted inside a hollow milling cutter. Machine coolant flowing through the cutter past the transducer forms an ultrasonic couplant between the transducer and the part. There is no mechanical contact. High frequency sound at 15 megahertz is emitted from the transducer into the workpiece. The elapsed time for the echo to return from the far side of the part is measured and converted to distance, or material thickness. Accuracy is ± 0.0005 inch at thicknesses up to 0.1 inch and ± 0.0010 at 2 inch thickness.

As machining progresses, part thickness is displayed instantaneously on the face of the unit's ultrasonic micrometer. At the same time, a digital printer records dimensions of the part on tape providing a permanent inspection record. Since the unit prints the X and Y location where each measurement was made, verification is simple; and manual point to point inspection of thickness is eliminated. Out of tolerance dimensions are printed in red, providing an automatic inspection flag. Thumbwheel switches control the dimensional spacing of measurements to provide grid type information. A selector switch also permits time or N/C tape print control options.

Auto Compensation Built In

An additional system capability just completed will transform errors detected by the ultrasonic sensor to N/C machine servo signals. The machine will then automatically compensate for unexpected part warpage and movement, maintaining thickness within tolerance. No operator action is required.



The ultrasonic measurement system in operation on a numerically controlled mill.

Huge Time Ratio Saved

Beyond the assurance of dimensions within tolerance, the system is a great time saver. Unlike the case of hand held ultrasonic instruments, no extra time is involved during machining. All measurements are taken while the cut is being made. The only additional time needed is that to calibrate the transducers and to scan the printout tape. The following tabulation summarizes the time savings (nearly 99 percent) realized on a typical 7 by 20 foot integrally stiffened panel.

$10 Million Annual Savings

Forging Costs Halved

"The most radical change in cannon manufacturing in the past 50 years!"—that is the description given by one project engineer to Watervliet Arsenal's new rotary forge method of large caliber cannon production.

The installation of the rotary forge has revolutionized this type of production at the Arsenal, bringing expected savings of nearly $10 million a year from over a 50 percent cut in forging costs. While conventional forging costs $1.70/lb, the rotary process using electroslag refined ingots costs only 70¢/lb. The forgings produced by the rotary process exhibit more uniform mechanical properties, better toughness, and longer fatigue life—all of which are important factors in the design of cannon weaponry. And a dramatic savings in energy consumption also is achieved.

Watervliet still is exploring the full potential of this innovative forging process, with its exciting future promise for industries which produce large cylindrical parts. Vast savings in labor, material, and energy are forecast. The savings in machining reductions alone could be astronomical, when one considers that estimates for the cost of metal removal go as high as $60 billion a year nationally.

18-Month Investment Payoff

Developed by an Austrian firm, Watervliet's rotary forge cost $15 million—an investment that the Arsenal will amortize in just a year and a half from reduced costs. Figures 1 and 2 are overhead views of the forge and its layout, showing the entrance and exit ends, respectively. This high production machine is capable of producing a tank cannon tube every 10 minutes, and it can be used for either hot or cold forging. The machine is 195 feet long and it weighs 935 tons—the largest of its kind in existence. It can forge tubes up to 33 feet with maximum starting diameters of 22 inches and minimum bores of 2.5 inches. Its action is described as "slamming four 1100 ton hammers simultaneously into a red hot ingot 200 times a minute", and it achieves a 5 to 1 reduction ratio in one forging pass. Because it produces parts closer to the final required (near net) shape, the machine allows tremendous savings in both time and materials as well as in energy consumption.

Numerical Controls, More Accuracy

The complete forging cycle (including loading and unloading) is numerically controlled, allowing greater dimensional precision. The operation is monitored by one man in an elevated, glass enclosed control room who is in radio contact with a floor man. Two television cameras with zoom lenses monitor the operation. A bore surface finish of 8 rms is attained with rotary forged tubes, which is better than with standard procedures. Wall thickness variations during hot forging range between 0.044 and 0.060 inch, with excellent repeatability due to the numerical control. The tubes appear to have a helix pattern on their surfaces, which results from the water spray used for descaling during forging; the hammers leave flat marks that lie in a straight line.

Thick Tubes Cold Forged

With the necessary tooling changes, high strength steel alloys in the 160 to 180 ksi range can be cold forged—the process probably will be used for thin walled cannon tubes where finished rifling also is required. In experimental runs, M206 recoilless rifle tubes having fin-

LEONARD LIUZZI is a Group Leader in the Metallurgical Processes Division at Benet Weapons Laboratory, Watervliet Arsenal. His current duties include primary responsibility for the installation and implementation of the rotary forge integrated line at Watervliet. Mr. Liuzzi is a graduate of Lowell University in electromechanical engineering. He also has pursued graduate studies in metallurgy, fracture mechanics, and deformation processing at Rensselaer Polytechnic Institute, the Massachusetts Institute of Technology, the University of Denver, and the University of Illinois. At Watervliet since 1961 he has conducted and supervised a wide variety of programs related to casting and forging processes for weapons manufacture and has published numerous technical papers in these areas. Mr. Liuzzi is a member of the American Society for Metals, serving on both the Forging and Swaging Committee and the Working and Forming Committee; the Society of Automotive Engineers, where he is on the Fatigue Design and Evaluation Committee; and the American Society for Manufacturing Engineers, where he is a member of the Engineering Materials Committee. He is also a member of the Tri-Service Advisory Group for Manufacturing Technology.

ished rifling were cold forged in a single pass with a reduction of 17 percent. The tubes were formed over a mandrel that contained a mirror image of the desired geometry and the proper helix angle of rifling. Rifling dimensions and tolerances equal to or better than those achieved through standard methods were attained, and the external finish of these tubes required no additional machining. The following tabulation compares a conventionally forged and a rotary forged 105-mm M68 gun tube.

	Conventionally Forged Tube	**Rotary Forged Tube**
Cold forge time	1 hr	10 min
Material cost	$1.70/lb	$0.70/lb
Beginning weight	8400 lb	3000 lb
Scaling	5%	0.5%
Tolerances	-0.120 OD +0.120 ID	-0.120 OD +0.060 ID

In other tests, full size howitzer tubes were cold forged from materials having initial yield strengths of 176 ksi. These thick walled tubes were forged in a single pass at an average reduction of 15 percent and the finished tubes were stress relieved at 800 F for 2 hours, then tested for mechanical properties. Cannon tube material specifications for both yield strength and ductility were met with transverse yield strengths of 163 and 166 ksi, respectively, in the muzzle and breech. However, toughness values fell below specification. This is believed to be the first time so large a volume of high strength steel was shaped in this manner to form a gun tube.

Less ESR Material Needed

Conventional forging of cannons starts with a rough machined air melt preform, which must be vacuum degassed, press forged, machined further, cored, heat treated, and tested for mechanical properties before it is shipped to Watervliet. There it is finish machined to the final shape for forging. During forging, it continually loses heat and must be put back into the furnace every two or three passes to recover its forging temperature; all of this is time consuming, with the forging operation alone taking an hour. In addition, an 8400 pound ingot is needed to produce a finished 1660 pound 105-mm cannon tube, and although most of the material lost can be remelted and recast, the extra labor and energy loss are costly. A hollow preform for forging made of electroslag refined material, on the other hand, has a starting weight of only 3000 pounds. The preform is preheated in one of four horizontal reduction furnaces which handle diameters up to 22 inches and weights up to 8 tons. The 3000 pound cannon blank will reach a forging temperature of 1900 F in 40 minutes, with forging requiring only 10 minutes.

Uniform Temperatures Maintained

A cast steel forging box comprises the case of the rotary forge machine, with four connecting rods arranged at right angles to each other within the box which are

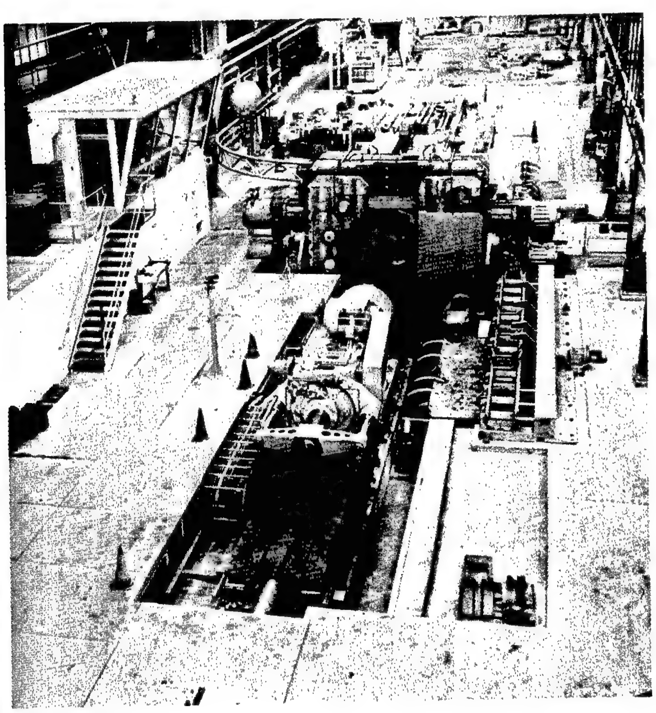


FIGURE 1

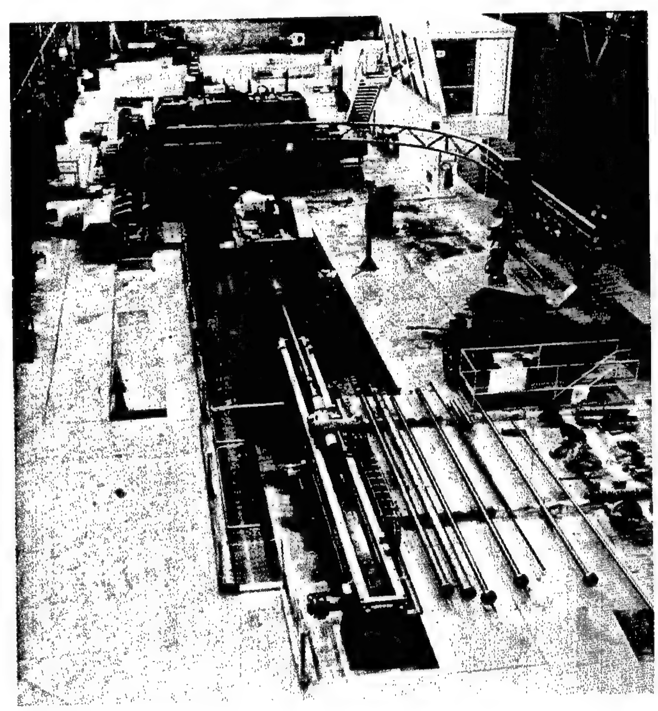


FIGURE 2

driven by eccentric shafts powered by two 800 hp motors. Four multiangle forging hammers—faced with nickel base tool steel—are mounted on the shafts. These hammers will last for 200 to 500 tubes, hitting simultaneously to provide a uniform temperature across the forging plane. The blank reaches the hammer at about 1850 F and when it comes out of the forge it is at about 1900 F. Rotating chuck heads are located at both ends of the forging box to support the workpiece and move it through the forging cycle.

After it is preheated, the preform is transferred to the chuck head at the entrance end of the forging machine (see Figure 3). As the chuck grabs the workpiece, a mandrel operating through a hollow spindle is moved through the workpiece until it is directly under the hammers. This is a floating mandrel that remains in position under the hammers throughout forging, ensuring proper bore diameter for subsequent finishing operations. This feature also permits cold forging operations.

Low Noise Level a Feature

The four axially located forging hammers are mechanically driven, and each time the hammers strike, rotation of the tube is halted to prevent twisting or tearing of the tube surface. The forging box absorbs the reaction forces of the hammers, unlike the open die processes which transmit these forces to the foundation. This prevents vibrations in the foundation and reduces the noise level to about 87 dB on the A scale.

As the tube proceeds through the forging box, the chuck jaw on the opposite end picks it up and pulls it through at the outgoing feed rate. This allows a tube to be worked its full length in a single pass, minimizing material loss. The hot forging rate is 3 fpm, five to six times greater than rates attained with conventional forging; cold forging proceeds at one third of that rate.

The outside dimensions of the forging are controlled by altering the stroke of the hammers, a change which makes it possible to forge different contours along the length of the cannon tube. This also allows two cannon tubes to be made from one forging using certain shapes by forging a thick middle section, which when cut in two gives each gun its breech while the smaller ends become the muzzles.

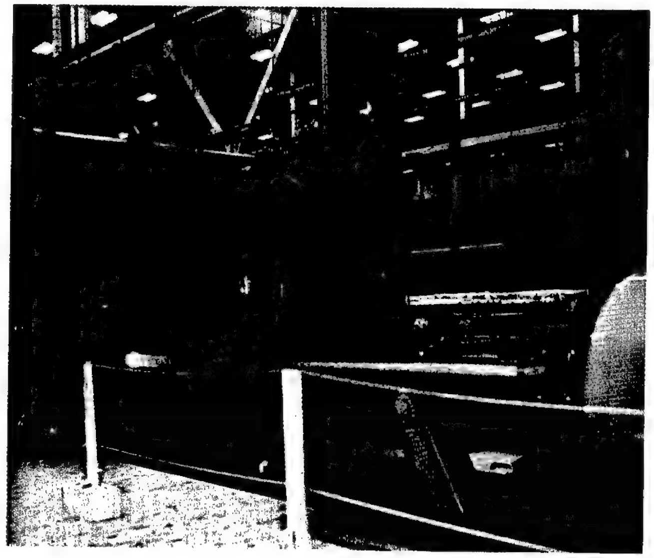


FIGURE 3

Heat Treatment Costs Quartered

Heat treating following forging to toughen the barrels is done in a 288 foot long system called a barrel line furnace, the name derived from the cylindrical shape of the furnace and not from the gun barrels treated in it. Whereas conventional heat treating of the 1660 pound cannon tube requires up to 30 hours, this system does the same job in only 8 hours. The tubes pass horizontally and continuously through the entire heat treat cycle. The furnace is divided into three zones: the high temperature (austenitizing) zone—60 feet; the rapid cooling (quenching) zone—43 feet; and the lower temperature (tempering) zone—84 feet. Open work tables comprise the balance of the 288 foot line.

For austenitizing, the cannons are loaded breech end first, allowing more time to get the heavier end up to temperature. The barrels move through the furnace on powered rollers at speeds of 0.14 to 0.35 fpm, with the rollers slightly skewed in order to slowly rotate the barrels as they move through the furnace.

The 105-mm tube is austenitized for 2 hours, 40 minutes at 1600 F, and the treatment on quenching gives a fully hardened 100 percent martensite structure through the entire cross section; a higher temperature would produce a coarser grain structure and reduce impact properties. The forging is moved quickly from austenitizing to the quenching station to prevent cooldown, then it is quenched over the entire length while being slowly rotated. The bore is quenched after external quenching begins, and to prevent cracking, the water flow, zoning, and quench cycle are controlled for each barrel size. During tempering, the cannon is held below 1200 F for 4 hours. The cost of heat treating the rotary forged 105-mm cannon is about $100, one fourth the cost of conventional practice.

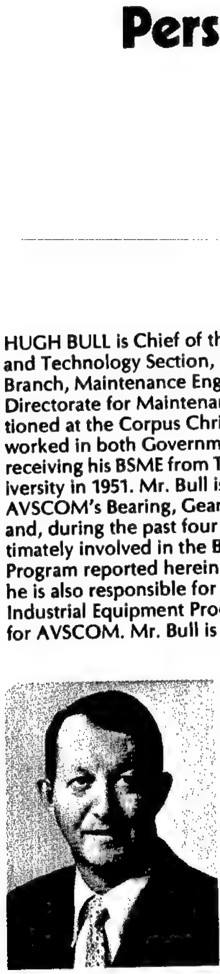
Joint Industrial Ventures Ahead

Many additional applications of the rotary forging process are anticipated that will improve the Army's manufacturing technology base. For example, it may be possible to hot work worn-out 155-mm howitzer tubes into 105-mm howitzer tube forgings. This would result in substantial materiel savings through conservation of alloying elements. Future joint ventures with industry should result in full exploitation of the rotary forge process for commercial applications.

Personnel, Equipment Losses Reduced

Inspection

HUGH BULL is Chief of the Industrial Processes and Technology Section, Engineering Support Branch, Maintenance Engineering Division, Directorate for Maintenance, AVSCOM, stationed at the Corpus Christi Army Depot. He has worked in both Government and industry since receiving his BSME from Texas Technological University in 1951. Mr. Bull is responsible for AVSCOM's Bearing, Gear, and Seal Programs and, during the past four years, has been intimately involved in the Bearing Inspection Program reported herein. In his present position, he is also responsible for the Computerization of Industrial Equipment Processes and Techniques for AVSCOM. Mr. Bull is a member of three DOD Bearing Committees.



HAROLD HATCH is a senior project leader in the Nondestructive Testing Industrial Applications Branch at the Army Materials and Mechanics Research Center, Watertown, Massachusetts. He holds a B.S. Degree in Physics from the University of Massachusetts. In 1966, he received the Department of the Army Research and Development Award for Technical Achievement for his work in the field of nondestructive testing. During the past four years, he has technically supervised the contractual efforts for the development of advanced instrumentation systems for inspecting high performance aircraft bearings. Mr. Hatch is a member of the DOD Ball and Roller Bearing Working Group.

A potential $20 million in savings has given the Army incentive to look at improved techniques for inspecting aircraft bearings. That $20 million is the amount that an estimated 16 percent premature failure rate is costing in premature overhaul. Even more important, these failures have contributed to the death of personnel and loss of aircraft.

Cost and failure rate figures were developed during a five year study by the Corpus Christi Army Depot. The study indicates that the use of effective diagnostic procedures and retirement schedules would have eliminated a large percentage of the failures and subsequent costs. Newly developed instrumentation facilities now installed at Corpus Christi show promise of meeting this need. As we continue to find answers through use of this new equipment, a significant reduction in the 16 percent failure rate can be expected.

"Infant Mortality" Rate the Target

The inspection problem is actually twofold. First, we must evaluate the condition of used bearings during scheduled overhauls. Of equal importance, we must evaluate new bearings before their installation in overhauled engines. Our studies in failure rate at Corpus Christi Army Depot are for "infant mortality"—i.e., failure occurring before the first scheduled overhaul (1200 hours for the T53 engine) after installation of a new bearing.

Metallurgical examination shows that many early failures of new bearings originate as small inclusions occurring just under the rolling surface of the bearing races (0.001 to 0.005 in.). In addition to subsurface inclusions, residual surface and near surface stresses in new bearings are intentionally introduced by various proprietary manufacturing processes. Plastic deformation of the raceways under load can cause these stresses to change during the life of the bearing. Our studies indicate that some of the infant mortality failures are caused by signifi-

Slows Bearing Failures

cant residual stress variations. These findings suggest an urgent need for nondestructive diagnostic equipment capable of detecting surface and subsurface defects as well as residual stress variations— in both new and used bearing components.

Cooperative Effort Identifies Needs

At the request of AVSCOM, and with their support, the Army Materials and Mechanics Research Center undertook a program designed to meet this need. The objective of this cooperative effort was to develop bearing diagnostic equipment capable of inspecting the wide variety of bearings used in Army helicopter jet engines and power trains. During the Summer of 1972, the authors began a review of Army requirements with respect to the inspection of bearings. We also sought to identify nondestructive evaluation methods for the detection of defects in antifriction ball and roller bearings. To accomplish these ends, we surveyed current literature and visited various companies and research centers involved with bearing diagnostics. From this effort, we concluded that three types of inspection hardware were needed, based on the following techniques:

- Magnetic leakage field techniques for the detection of subsurface defects in new bearing raceways
- The magnetic Barkhausen technique for measurement of residual stress in bearing components
- The dynamic acoustic analysis technique for the detection of service induced damage in used bearings.

To procure this hardware, contracts were awarded to Mechanical Technology, Incorporated (MTI), for development of dynamic bearing analyzers and to Southwest Research Institute (SWRI) for development of instrumentation based on magnetic perturbation and Barkhausen evaluation methods.

MTI Method Effective For Used Bearings

MTI designed and constructed one analyzer for the inspection of fully assembled ball bearings and a second for roller bearings. The former has a vertically oriented spindle including provisions for the application of both axial and

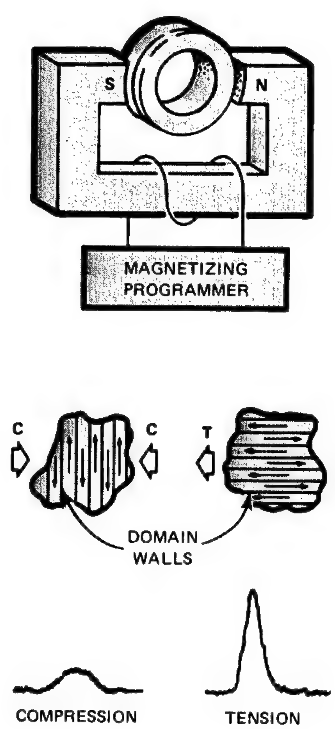


FIGURE 1

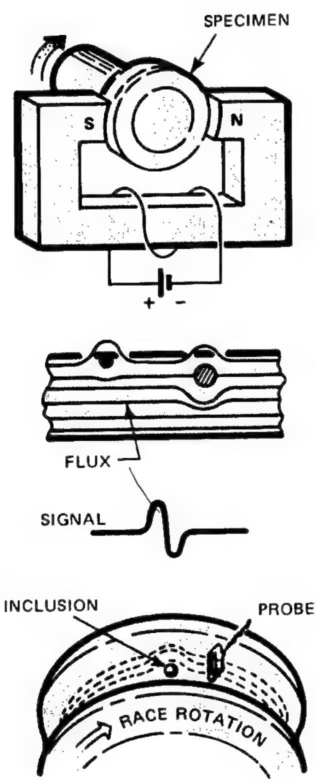


FIGURE 2

radial loads. The latter has a horizontal spindle equipped for radial loading only. These analyzers employ the high frequency resonance technique (HFRT) developed previously by MTI for fault detection and identification.

Each unit consists of (1) a mechanical console on which the test bearing is mounted, loaded, and brought up to speed and (2) an electronic console which processes the output of a wideband transducer mounted on the bearing retainer. The units have identical electronic consoles.

When a rolling element encounters a surface defect, it generates a mechanical impulse which in turn excites a race resonance. This resonance is detected by the console transducer. The instrumentation not only detects defect signals, it identifies the signal source. Nine signal processing channels generate output data for a matrix of various combinations. Each set of combinations can be uniquely related to the occurrence of a specific fault. Selective filtering determines the origin of the defect signal—i.e., in the inner race, outer race, rolling elements, or cage. It also distinguishes surface roughness effects from discrete spalls or pits. Similarly, once per revolution signals often associated with unbalance or runout and twice per revolution signals associated with misalignment can be separated.

The mechanical impulse technique is effective only for surface defects; it will not detect subsurface inclusions in new bearing races. The method is directly applicable to the detection of service induced surface damage in used bearings, especially nonseparable bearings that cannot be disassembled without destroying one or more bearing components.

SWRI System Combines Two Techniques

Southwest Research Institute brought more than 10 years of experience in the development of nondestructive bearing evaluation methods to its part of the program. This prior work provided the technical basis for the design and construction of sophisticated prototype hardware that integrates magnetic perturbation and the Barkhausen noise technique into a single inspection system.

Figure 1 is the Barkhausen stress measurement technique. Barkhausen noise consists of voltage pulses generated in induction coils by abrupt movement of domain walls. SWRI utilizes this phenomenon to assess residual stress, applying a controlled but changing magnetic field to force movement of the domain walls, electronically

processing the pulses, and obtaining an analog signature. High amplitude signatures indicate tension regions and low amplitude signatures indicate compression regions.

In magnetic perturbation, a magnetic flux is established in the region of the material being inspected. A sensitive magnetic probe then scans the surface to detect anomalies or perturbations in the magnetic flux caused by voids, inclusions, or local metallurgical variations. Figure 2 illustrates the concept. In practice, the bearing race is rotated at a constant speed. A small coil type probe, coupled to the bearing surface by means of an air cushion, senses the magnetic perturbations (signatures) from a scan track approximately 0.025 inch wide. Metallurgical sectioning and endurance testing confirm the effectiveness of the method.

Figure 3 shows a typical inspection record and results that confirm a subsurface inclusion. Prior to sectioning, fine scribe lines are made in the region of the signature and a record is obtained with an expanded horizontal axis. The scribe line signatures provide references that permit precise location of the signature of interest. The expanded signature provides a basis for estimating the approximate depth of the flaw.

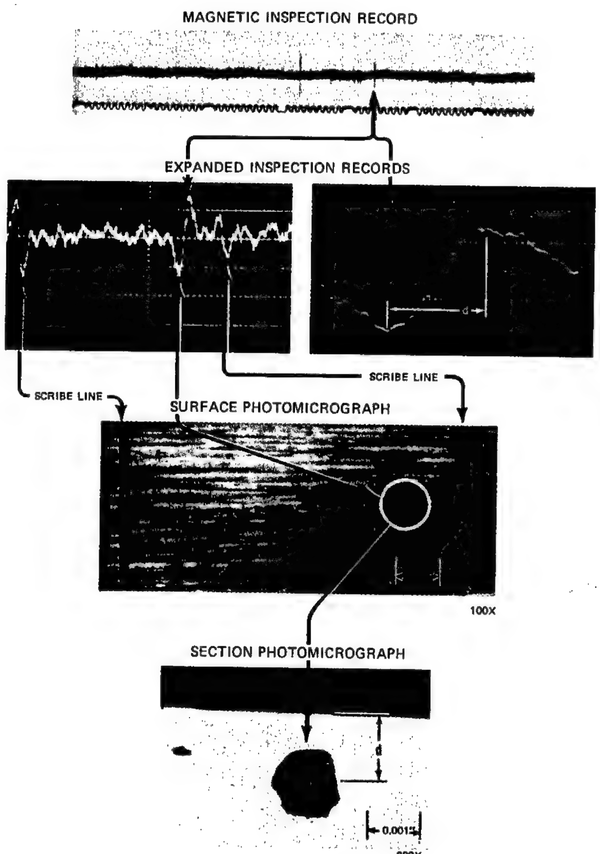


FIGURE 3

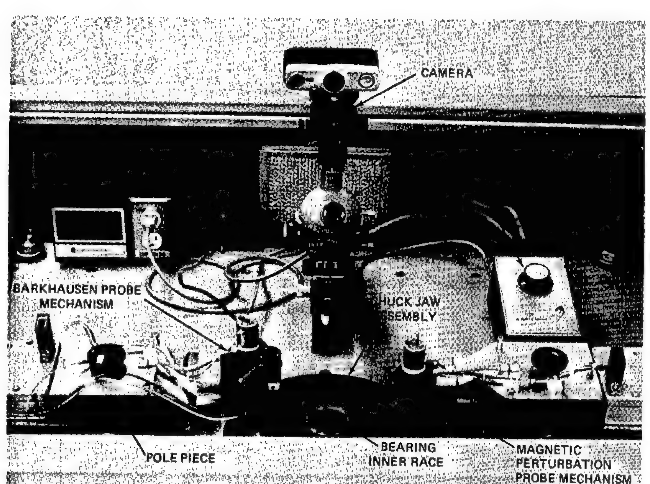


FIGURE 4

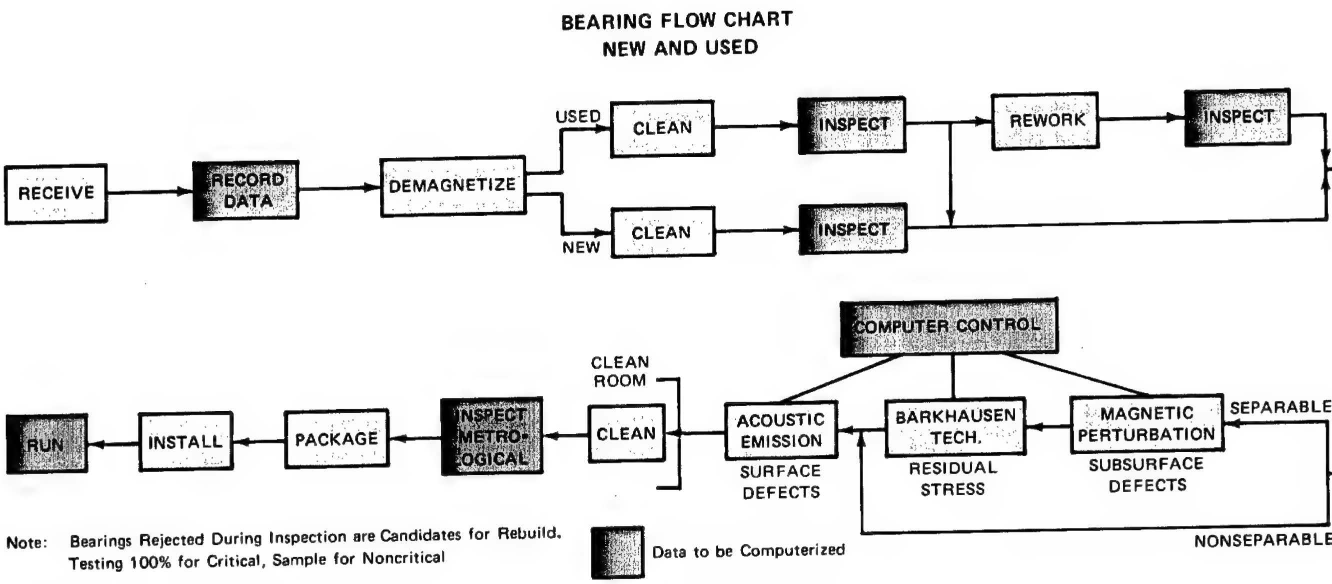


FIGURE 5

On the prototype system, magnetic perturbation and Barkhausen measurements are recorded sequentially. A minicomputer data acquisition system integrated with the mechanical, electrical, and electronic subsystems controls all functions. Figure 4 is a closeup of the mechanical scanning assembly. By means of the teletype terminal, the operator notifies the computer of the specific bearing component to be inspected. The computer then prints out the pole piece, spindle adaptor or chuck, and the parameter tape required for the inspection. The operator installs the two pole pieces and the chuck assemblies called for, selects the appropriate preprogrammed tape containing the inspection parameters, and enters these parameters by processing the tape through the high speed paper tape reader. Inspection parameters include mechanical sequencing of operations, spindle rotational speed, magnetizing current values and sequences, number and location of individual scan tracks across the bearing contact surfaces, and pole piece locations.

Bearing Failure Predictions Next

Both the MTI and SWRI instrumentation systems are now installed and operating at the Army's new worldwide service bearing facility located at Corpus Christi Army Depot. However, we do not yet have all the answers; for instance, very little is yet known about predicting bearing failures. To meet this need, the instrumentation systems now in line in the bearing inspection cycle (Figure 5) will collect data over the next few years for engineering life extension studies of both new and used bearings. This data will be used to establish accept/reject criteria.

Another area of critical importance to the Army is extending the service life of bearings and learning why 16 percent fail prematurely. Lead time for acquisition of new bearings has dramatically increased in recent months to the point that refurbishing of critical bearings is becoming mandatory. And, in some cases, acquisition costs have risen over 300 percent. Extended life is a must.

US Army

ManTech Journal

An Integral System That Works

Volume 2 / Number 3 / 1977

THE MANTECH JOURNAL is published quarterly for the U.S. Army by the Army Materials and Mechanics Research Center, Arsenal Street, Watertown, Massachusetts 02172, through the Metals and Ceramics Information Center, Battelle, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

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US Army
ManTech Journal

Contents

ABOUT THE COVER:

The 155-mm gun barrel shown on the front of this issue of the *Army ManTech Journal* is being forged on ARRADCOM's new rotary forge at Watervliet Arsenal. The four hammers of this immense new tool are shown immediately after striking the tube, and the effects of the work can be seen in detail in this dramatic photograph by Ralph Goodrich, staff photographer at Battelle. Striking at the rate of 200 blows per minute, the four hammers can finish forge a large caliber gun barrel in 10 minutes, with rifling provided by the shaped mandrel positioned inside the barrel directly beneath the hammers.

Comments by the Editor

DR. JOHN J. BURKE

Spreading the word on the broad manufacturing technology program under way in the U.S. Army has been the purpose of the ManTech Journal since its inception. This dissemination of technological information that is hard for many other publications to come by has been preeminently successful, judging from the reception of the Journal during its first year of existence. This issue completes the first year of publication which started with the first pilot issue of Fall 1976. Those receiving the magazine include the technical libraries of many large firms that are determined to keep abreast of the state of the art in manufacturing. Also, a large number of engineers and scientists in both government and industrial research laboratories as well as in academic pursuits maintain their awareness of new manufacturing developments through the ManTech Journal. This is particularly true for articles on munitions manufacturing processes, which have been in every issue. This area of production in the United States is a uniquely governmental function.

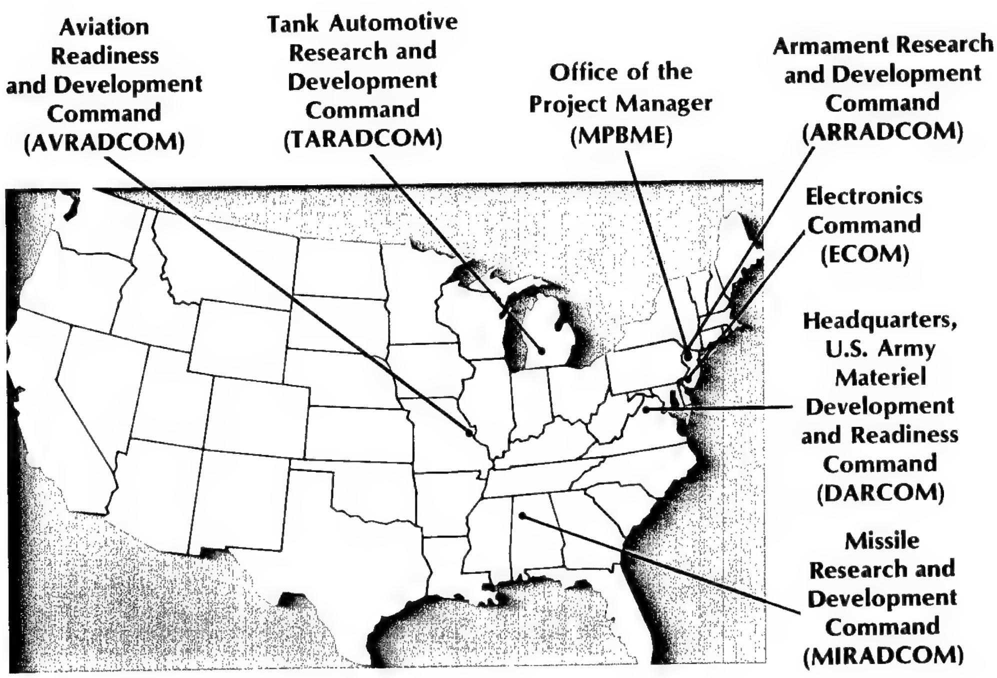
We are pleased to present to our readers in this issue a report on one of the best examples of modern management in the military services, with the articles featuring ARRADCOM and the establishment of a fully integrated, systems oriented command. The new organization represents the culmination of several years of careful analysis and planning for the purpose of consolidating the elements of research and development in the munitions and weapons area of production under the management of only one organization. Outstanding accomplishments were expected, and several already have taken place; the articles in this issue of the ManTech Journal tell of several of these achievements. Subsequent issues will further outline the results of ARRADCOM's efforts in manufacturing technology.

The next issue of the ManTech Journal will feature articles based upon highlights of the DOD/Industry Chip Removal Conference held in early 1977 at Daytona Beach. This conference reflected the growing sense of cooperation and common purpose shared by the military agencies and industry, as they face the same technological challenges of the late '70s and '80s. These challenges were predicted formally in the GAO Report of 1976 on Manufacturing Technology in the United States but were foreseen several years before by planners within the Army. These predictions are only too clearly illustrated to manufacturing engineers in both the military and in industry by the bleak reports being received on our national economy and our growing trade deficits. The Army's

foresighted decision to launch a major manufacturing technology effort early may well become a major factor in the battle to reverse these undesirable and ominous economic trends.

The first issue of the ManTech Journal for 1978 will contain a series of articles reporting on the achievements of the Aviation Research and Development Command. Several of these articles will be topics at the November 1977 Conference in Palo Alto on Army Aviation Manufacturing Technology, and the lineup looks like one of high interest—not only for those working in aircraft manufacturing but also for those in the automotive and other fields. These areas of manufacturing now are beginning to heavily use the new array of composite materials that constituted a major part of the topics for the conference.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



"Marketing" Precepts Followed

A New Spirit in Armament Manufacturing

In his inaugural speech on January 20, 1976, President Carter spoke of the "New Spirit" which will characterize the coming years of his administration. I would like to observe that we, too, at the Armament Research and Development Command (ARRADCOM), have a "New Spirit" which will renew and invigorate the armament development community. The source of that "New Spirit" does not lie in the building or renovation of structures, nor will it come from bringing in new equipment, although we will be doing both of these things. It will not come from a sudden influx of money or programs, although we will inherit an impressive budget and an extensive list of development programs. The source—as well as the manifestation—of the "New Spirit" will be the people who are members of ARRADCOM, together with the community in which we live and work and the business community with which we are associated.

We have come an amazingly long way since the first recommendation was made that the armament research and development community should be drawn more tightly together and given its own full-time management. Many conceptual, legal, financial, and procedural obstacles have been overcome in reaching the point at which we stand. We have endured our birth pains—the years of preliminary studies, the planning process of reorganization, and the reorganization itself. Now we have begun our rapid growth to maturity.

I would like to introduce you to the mission and organization of ARRADCOM and to our new way of doing business.

MAJOR GENERAL BENNETT L. LEWIS is Commander of the US Army Armament Research and Development Command (USARRADCOM) at Dover, New Jersey. He assumed those duties on January 31, 1977 after leaving HQ ARMCOM at Rock Island Arsenal in Rock Island, Illinois. The HQ ARMCOM was subdivided into R&D (ARRADCOM) and readiness (ARRCOM) commands. General Lewis was assigned to the most complex of the Army's organizational realignments after completing an assignment as Special Assistant to the Commander of DARCOM responsible for the Study of The AMC Committee—Armament. A 1950 graduate of the U.S.Military Academy, General Lewis has had several assignments in Research and Development in the Army. He has a Master's Degree in Civil Engineering from Harvard and also is a graduate of the Command and General Staff College, the Engineer School, and the Army War College. He was born in 1926 in Boston, Massachusetts. Before being assigned as a Special Assistant to the Commander of DARCOM, the general was the Chief, Requirements and Developments Division, for the Joint Chiefs of Staff. He was Commander of the 14th Engineer Battalion, Pacific-Vietnam, and subsequently was Assistant Chief, Construction Division, Engineer Office Vietnam. After his tour in the Army War College, the general became the Commander and Director of Research, Development, and Engineering, USA Mobility Equipment Research and Development Center, which initiated his career in Army research and development.

Faster Development Needed

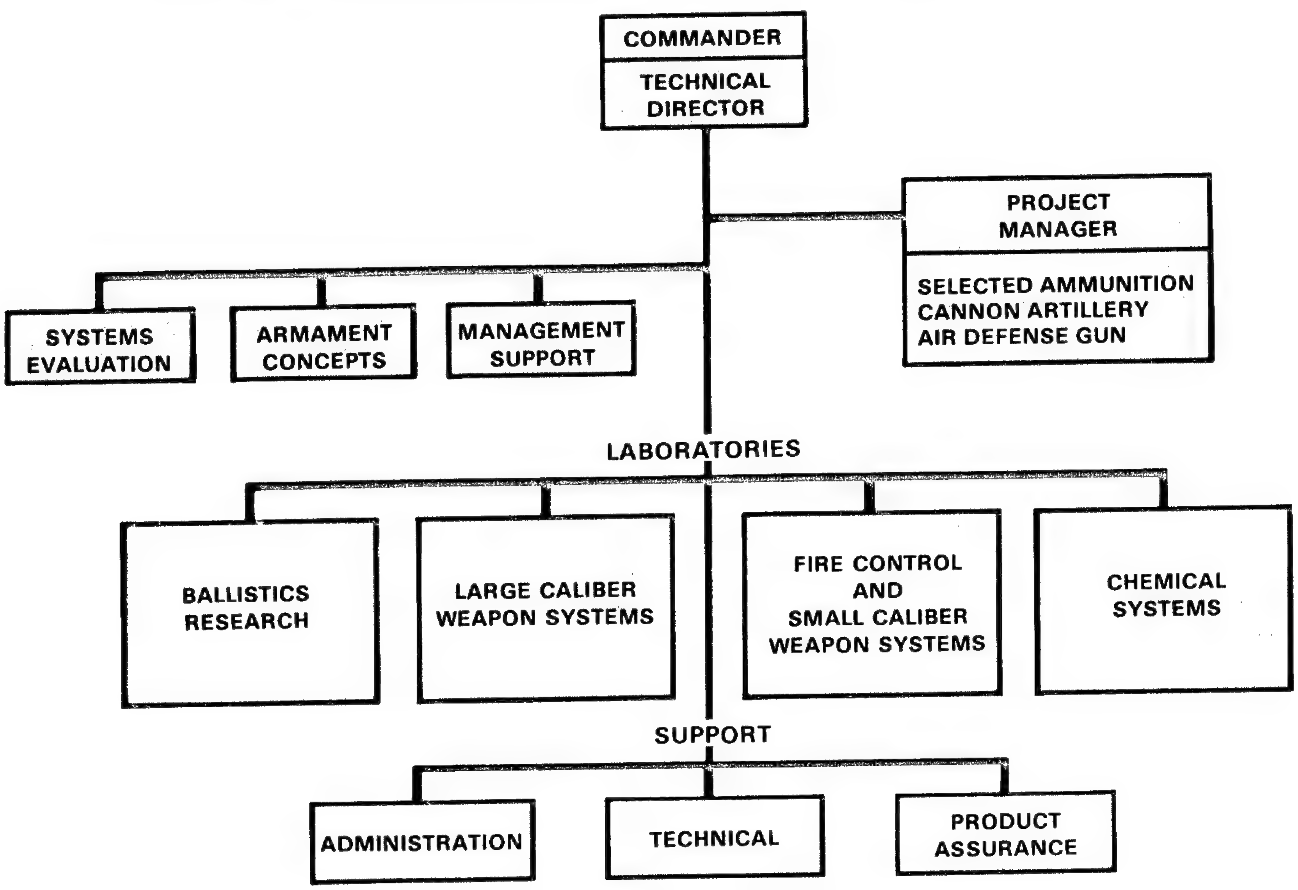
To understand why we are doing business in a new way, you must appreciate the difficulties we have experienced in doing business the old way. First, the old way was not all bad. Logistics support (materiel readiness) was generally good. The soldier in Viet Nam never lacked for weapons or ammunition. Many individual R&D project elements, product improvements, and engineering change proposals were well executed. Most important, the employees were professionally competent, dedicated, and hardworking. But neither was the old way all good. A review of the past showed that an inordinate amount of time was required to develop new systems—eight to fifteen years was typical. Over the span of many years, input was not being balanced by output. By that, I mean that the one quarter to one half billion dollars a year in RD&E was not providing us the quality or the quantity of new and improved weapon systems that one would expect. The bulk of our serious technical problems involved a poor interface between organizational elements and project components.

A New Way of Doing Business

As we dug more deeply in search of the causes, the major reasons for these problems became apparent. Our R&D structure was fragmented within arsenals and

between arsenals, with emphasis on component rather than systems development. At the Armament Command (ARMCOM) headquarters level our directorates attempted to pull the component work into a systems structure. R&D management was a part-time job for the ARMCOM commander and for most of the arsenal commanders. Organizational layers and barriers between the various parts of the armament research and development community were excessive. The systems elements—the gun, the bullet, and fire control—were not jointly developed at the bench; they were pulled together only at the ARMCOM headquarters level. There was a tendency to be sympathetic to proposals developed in-house and to be hypercritical of proposals from outside—the familiar "not invented here" syndrome. Points of entry into our system for industry representatives were varied and scattered. Perhaps most critically, personnel development and advancement were restricted by geographical separation and compartmentalization. With problems like these, change was clearly in order. Simply stated, the objective was to develop a new way of doing business which would preserve the good points of the past while correcting the weaknesses.

U.S. Army Armament Research & Development Command



Full-Time Management Established

With the creation of ARRADCOM, we now have full-time high level management which is responsible for research, development, and initial production. This will make sure that the item developed will be producible in quantity.

Several organizational changes were prerequisites to making additional mangement changes. The Ballistics Research Laboratory (BRL) has joined the command. The Armament Materiel Readiness Command (ARRCOM) is responsible for those functions of materiel management from time of fielding of the item until it is obsolete. ARRCOM is in close contact with the field user, and the Armament Research and Development Command (ARRADCOM) is in close support of ARRCOM. Within ARRADCOM headquarters and the two weapon systems laboratories at Dover, New Jersey, we have the bench-level collocation of scientists and engineers. I would like to stress that this is not movement for movement's sake, but an essential step in improved management.

In the center of the ARRADCOM organization chart are the major "doing" elements of the command: the Ballistic Research Laboratory and the three systems laboratories—Large Caliber Weapon Systems, Fire Control and Small Caliber Weapon Systems, and Chemical Systems. To address the problem of poor interface between components, we now have a systems oriented organization to replace the previous component oriented organization. The new organization and geographical concentration will provide propitious conditions for development and motivation of our talented personnel.

Given full-time management, a high degree of collocation, and a system oriented structure, additional management improvements have become possible. Management layers and barriers have begun to fall away, allowing simpler, more expeditious coordination. Bench level coordination and the transfer of technological information among scientists and engineers have become more likely, because the participants are physically located in the same geographical area instead of being hundreds of miles apart in separate arsenal organizations.

Personnel Upgrading Improved

Management options for advancement of best qualified personnel also have been enhanced by bringing together the mass of weapon system developers. Working in systems laboratories with more opportunities for periodic broad gauge staff and project team duties facilitates the development of people who are truly systems oriented in their thinking. The sizable concentration of armament research, development, and engineering personnel makes it possible for us to start an institute of armament technology for continuously upgrading personnel and for establishing a base of scholarship in the unique aspects of that technology.

Within the organization, specific measures will improve our output orientation. We have ended the favored treatment of the in-house developer by making him sign a contract type of agreement with top management that imposes the same kind of dollar and time constraints on in-house efforts that we have traditionally imposed on outside contractors. There has been a shift in emphasis toward evolutionary low risk, bite size improvements which should reduce development time for fielding improved systems, in contrast to the long-term efforts devoted to high risk projects that depend on new state-of-the-art technology. Our organization includes a small group of "Marketers" within the Armament Concepts Office who will work full-time to meet customer demands and to push developers to meet deadlines. They will also keep abreast of what industry, private research organizations, foreign countries, and the other armed services have to offer.

Performance Evaluated

We are forming channels for a closer customer involvement in (and better understanding of) the development processes and the need to minimize fluctuating requirements, once a development process has begun. We have established an office which evaluates the performance of the rest of our organization in meeting its corporate goals.

I mention these various measures because I want to emphasize that we have tried to be our own most severe critic. After reviewing past performance, I feel we have learned our lessons well. We have started the assembly of a critical mass of talent which will produce a chain reaction of fruitful research, development, and engineering effort to improve the quality of the product and the process in the field of armament systems. In pursuing this goal, an additional advantage has accrued in the form of a more efficient, economical operation which will be of long-term benefit to every American taxpayer.

Emphasis on Mission and MM&T

COLONEL ROBERT B. HENRY is Chief of the Program Management Support Office, principal advisor to the Commander on corporate or decentralized management planning, trends, resources, and objectives for ARRADCOM. His office serves as the primary staff element in ARRADCOM for Manufacturing Methods and Technology. Colonel Henry previously served as Commander, Radford Army Ammunition Plant, following his assignment as Commander of the Army Materials and Mechanics Research Center. A 1955 graduate of West Point, he received his Masters Degree in Chemistry from Penn State and returned to West Point to serve as an Assistant Professor. He has obtained his Ph.D. in Science Education from Boston College.

The Armament Research and Development Command (ARRADCOM) is vitally interested in a wide spectrum of improved manufacturing processes since Manufacturing Methods and Technology (MM&T) is an important ARRADCOM responsibility, and the Command's activities in this area directly affect many elements of the Army's mission.

Just as our development items are destined for support of the Training and Doctrine Command (TRADOC)—representing the user—so our efforts in developing new and more efficient manufacturing processes are destined for the corresponding Readiness Command as the user.

Weapons, Ammunition and Other Procurement, and Manufacturing Methods and Technology (MM&T) programs at ARRADCOM must support the following mission areas:

- Close combat
  - Mechanized infantry
  - Tank/antitank
  - Combat aviation
  - Light weapons
- Fire support
  - Cannon artillery
  - Mortars
  - Guided projectiles/rockets
- Other combat support
  - Mine/countermine
  - Nuclear/biological/chemical
- Air defense
- Chemical/biological defense

Responsibilities Extensive

The organization of ARRADCOM, as discussed in the article by General Lewis, emphasizes a systems orientation—large caliber systems, small caliber systems, and chemical systems. This orientation facilitates the timely insertion of Manufacturing Methods and Technology programs in the development/production cycle. ARRADCOM—as the other new development Command in conjunction with ARRCOM—has responsibilities far beyond R&D:

- Production Base Support
  - Initial Production
  - Manufacturing Methods and Technology
  - Materials Testing Technology
  - Military Adaptation of Commercial Items
- Continued Engineering Support
- Maintenance of Technical Data Package
- Product Improvement

In fact, a majority of our funding is Procurement Appropriation, Army, rather than RDT&E. The interest, then, in Manufacturing Methods and Technology is more than a corollary one—processes and production engineering support are primary areas of responsibility.

Laboratory Expertise Used

The Manufacturing Methods and Technology responsibility at ARRADCOM has been located at the individual laboratory level. Each laboratory has a Manufacturing Methods and Technology element to ensure a close working relationship to developmental expertise. The Program Management Support Office is the headquarter's element responsible to ensure the Command's response to Manufacturing Technology. Finally, there is an Associate Technical Director whose efforts are devoted exclusively to advanced process technology and who is responsible to the Technical Director for this area.

Advanced process technology spans a wide variety of effort in support of the mission areas cited with work conducted at the laboratories, industry, and the Government owned, contractor operated plants. Because of the wide span of responsibility and the past emphasis on munitions, the ARRADCOM Manufacturing Methods and Technology program is appropriately large.

ARRADCOM's response to this vital program is a continuing and enthusiastic devoting of all of the Command's talents to ensure its success. Some of these vital programs are discussed in detail in the succeeding articles.

What and Why ARRADCOM?

It is with pride that the U.S. Army Armament Research and Development Command (ARRADCOM) has been selected to be featured in this issue of the ManTech Journal. To some the question might arise, "Why is a research and development command the topic of a manufacturing technology journal?" Too often, perhaps, we fail to recognize that the research and development command is a center of engineering expertise concerned with both item and manufacturing process development. In order to view ARRADCOM in the proper perspective, it must be considered as a technical center dedicated to the research, development, and engineering design of armament systems and the processes by which these systems are produced. The ultimate purpose, of course, is to provide the finest armaments possible to our combat soldiers.

DONALD J. FISCHER is a Senior Program Analyst in the Program Management Support Office of the U.S. Army Armament Research and Development Command. His responsibilities provide for program management and analysis of a variety of Manufacturing Technology efforts conducted throughout the Command, particularly relative to the support and development of a viable Manufacturing Methods and Technology Program for Ammunition and Weapons. He is a graduate of Rutgers University, receiving a Bachelor of Science Degree in Accounting and Business Management in 1953. Prior to his assignment at ARRADCOM he was Chief of the Technical Programs Division, Manufacturing Technology Directorate, Picatinny Arsenal, from 1972–76. In April 1976 he was selected to join the ARRADCOM Implementation Task Force which was assembled to spearhead the establishment of the new Command in March 1977. In 1973, he, together with a group of engineers, received the Department of Army Materiel Acquisition Award for developing a comprehensive Manufacturing Methods and Technology Program for the Abatement of Environmental Contamination in the Ammunition Manufacturing Complex of the Army. He is also a member of the Manufacturing Technology Advisory Group for Munitions.

Composite Formed

ARRADCOM is new, but most of its engineering efforts are not. The recent reorganization brought together the activities of former arsenals or commodity centers so that the engineering base could be solidified and provide a more positive base for the interplay of engineering talent. ARRADCOM is a composite of Picatinny Arsenal, Frankford Arsenal, Edgewood Arsenal, Ballistics Research Laboratory, Benet Weapons Laboratory of Watervliet Arsenal, and Rodman Laboratory of Rock Island Arsenal. Each of these commodity centers has played a significant role in support of the production base support program. Extensive process engineering was performed that was directly related to large scale procurement of ammunition and weapons. Of considerable importance is the fact that the underlying research capabilities of the Ballistics Research Laboratory have also been brought to bear in a very direct way in the accomplishment of these programs.

The core of ARRADCOM is its operating laboratories. The efforts of the former commodity centers for both item and process technology has been realigned and placed into four major technology centers or laboratories: the Large Caliber Weapons Systems Laboratory, the Fire Control and Small Caliber Weapons Systems Laboratory, the Chemical Systems Laboratory, and the Ballistics Research Laboratory. Within these laboratories the bulk of the manufacturing methods and technology program is managed and executed. Additionally, the laboratories provide support to the facilities' modernization and expansion program.

What is significantly clear is that we are fully systems oriented. The ammunition component is not developed in an installation separated from the weapon developer. Not so fully realized but of equal significance is that we now have the product developer collocated with the process developer.

Surrounding these four major technology centers are a number of important support organizations on which the item/process developers must rely, such as the Product Assurance Directorate, the Technical Support Directorate, and the Procurement Directorate, together with other staff elements.

Two Principal Users

In its efforts to support the production base manufacturing technology program and the thrust of that technology as it applies to the facility modernization and expansion program, close coordination is essential; this coordination is maintained through two principal "users" of the process technology expertise assembled in ARRADCOM. These are the U.S. Army Armament Readiness Command and the Project Manager for Munitions Production Base Modernization and Expansion.

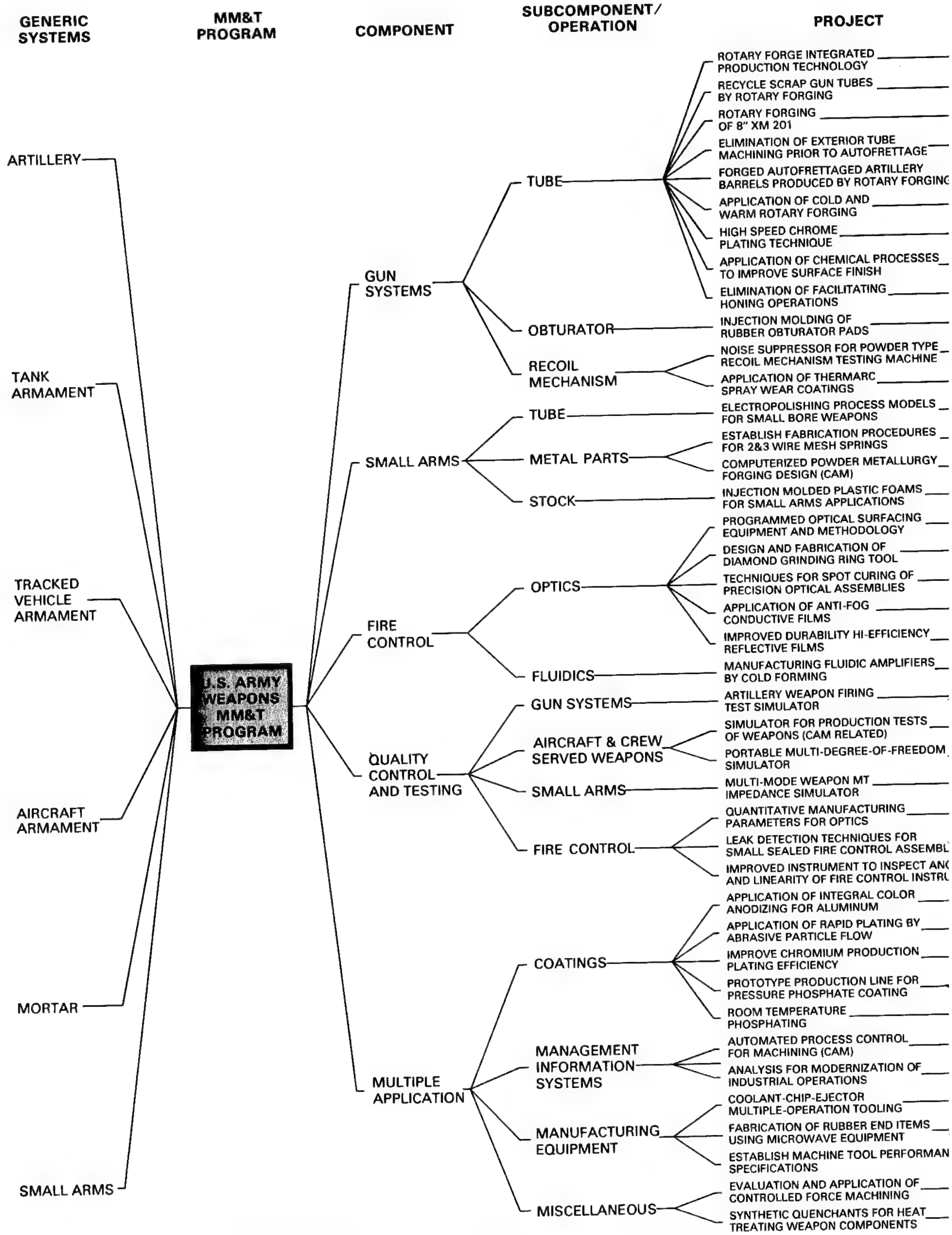
Utilization of modern manufacturing technology is mandatory if the needs of our modern combat units and forces are to be met. The sophisticated weaponry being developed requires high levels of production reliability and safety, and of increasing importance is the need for weapon systems that are within acceptable economic limits. The design engineer therefore must design the weapon system not only to meet performance characteristics but for mass producibility and cost acceptability.

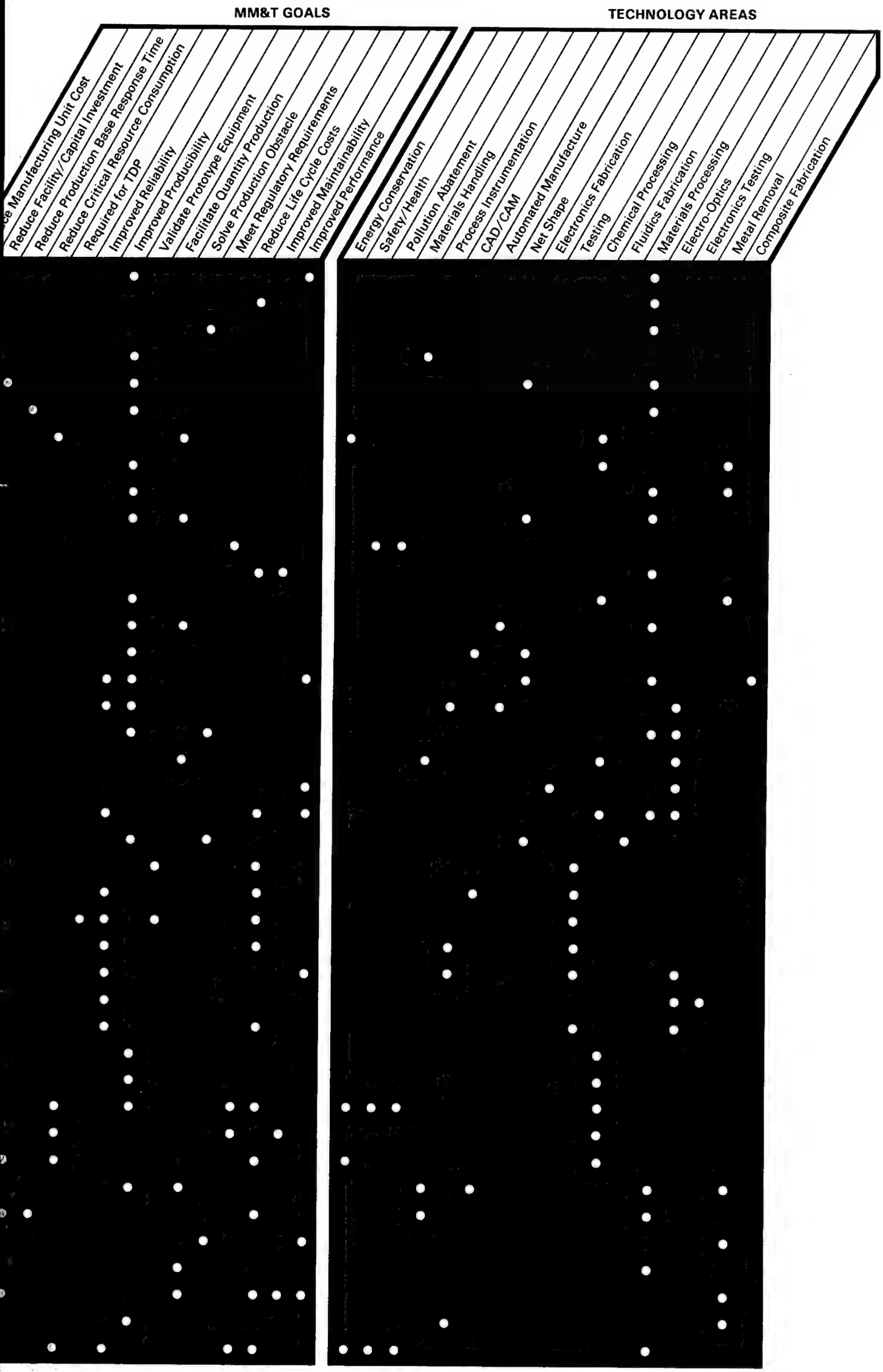
The "New Way of Doing Business" at ARRADCOM brings the requisite interfaces of scientific and engineering expertise closer together than ever before and heralds a dedicated, coordinated effort to surmount the many difficulties of materiel development and acquisition.

SPIDERCHART

MM&T PROGRAM: U.S. ARMY ARMAMENT MATERIEL READINESS COMMAND AND U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAN

Editor's note: ARRADCOM Manufacturing technology projects referred to on the SPIDERCHART relate only to weaponry, which represents one-half of the R&D house at ARRADCOM. The other half—munitions—was thoroughly covered in the initial issue of the ManTech Journal, with those projects shown on the SPIDERCHART in that issue.

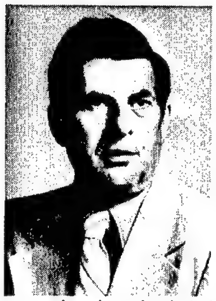



MM&T GOALS
ce Manufacturing Unit Cost
Reduce Facility/Capital Investment
Reduce Production Base Response Time
Reduce Critical Resource Consumption
Required for TDP
Improved Reliability
Improved Producibility
Validate Prototype Equipment
Facilitate Quantity Production
Solve Production Obstacle
Meet Regulatory Requirements
Reduce Life Cycle Costs
Improved Maintainability
Improved Performance
TECHNOLOGY AREAS
Energy Conservation
Safety/Health
Pollution Abatement
Materials Handling
Process Instrumentation
CAD/CAM
Automated Manufacture
Net Shape
Electronics Fabrication
Testing
Chemical Processing
Fluidics Fabrication
Materials Processing
Electro-Optics
Electronics Testing
Metal Removal
Composite Fabrication

Pioneering The 21st Century

Highlights of Major Achievements

This issue of the ManTech Journal, featuring the Armament Research and Development Command, points to significant changes in operation within the ammunition and weapons producing segment of the U.S. Army. Articles are presented on the design of new ammunition plants, new ways of handling products automatically, expanded application of the computer in developing laboratory processes into production processes, use of the computer to speed up mobilization rates, and application of design to unit production cost techniques. These illustrate important applications and uses of ARRADCOM's weapon and ammunition expertise in support of the item and process development. Such efforts will revamp the Army's production facilities into the most modern, effective system in the world. These developments are designed to save the materiel and financial resources of the nation and at the same time provide the Army with the most advanced weaponry possible. These highlight articles are followed by Brief Status Reports on ongoing manufacturing technology projects—projects that will bear fruit in the coming years.



WERNER FIELD currently is a Supervisory Mechanical Engineer at ARRADCOM in the Non-Nuclear Munitions Division of the Large Caliber Weapons Systems Laboratory. He received his Bachelor of Chemical Engineering Degree from C.C.N.Y. (1948) and his M.S. from the Stevens Institute of Technology (1953). Mr. Field joined the staff at Picatinny Arsenal in 1948, working on production engineering of fuze components. Over the years, he became involved in more and more diverse phases of ammunition production, covering metal parts manufacture as well as load, assembly, and pack (LAP) operations, with assignments also in the quality control and methods fields. When work on the Integrated Large Caliber (ICM) complex began at Picatinny, he became the coordinator for the grenade metal parts production and the LAP operation.

HOWARD I. HUFF began his career with the Army as an enlisted man in the Scientific and Engineering Program at Aberdeen Proving Ground after receiving his B.S. Degree in Engineering from Rutgers University in 1960. Following his discharge, he joined the staff at Frankford Arsenal as a Design Engineer for Propellant Actuated Devices. When Frankford Arsenal began development of the 155-mm M483 ICM projectile in 1963, Mr. Huff assumed the duties of project engineer. Since that time, he has been involved as a project engineer in many phases of the M483 projectile program, including initial concept, engineering development, initial production, and expansion of production facilities. He currently is also working in the Non-Nuclear Munitions Division of the Large Caliber Weapons Systems Laboratory.

New Ammo Plant Design Reflects Milestone

First in Over 30 Years

When the Army elected to construct a separate facility to meet future production needs for M483A1 projectiles, it marked the first opportunity since World War II to build a new ammunition plant "from the ground up". The design effort for this massive undertaking was assigned to a Frankford Arsenal-Picatinny Arsenal team now in ARRADCOM. There were many who thought that the task of laying the groundwork for so large a project was too formidable to be handled in house. Did ARRADCOM engineers have sufficient background? Also, were sufficient resources available?

With plant construction currently under way, a dedicated and enthusiastic group of engineers now has quieted skeptics. The new complex ensures more efficient overall operation; and in the process of laying out the facility, engineers were afforded a close look at individual operations, with the result that many cost saving innovations have been incorporated. The careful plans made at ARRADCOM now are undergoing the close scrutiny of an operating contractor who wants a plant that "works". The record of ARRADCOM's efforts in designing this facility is instructional and should encourage future projects of this nature to be undertaken.

The Beginnings

As noted, a project of this nature was unprecedented in recent years. Many conversion and expansion projects have been carried out, but none were on so vast a scale as the Integrated Large Caliber ICM Complex discussed here.

The decision to build a dedicated facility for M483 production was made by the Project Manager for Base Modernization and Expansion (PBM). The advantages had been proven of an integrated complex—a combined metal parts and loading facility—with all that is to be gained from planning and operating "under one roof".

ARMCOM made the original make or buy decisions. They decided that the new facility should produce all components for which a sufficient commercial base was not likely to be available during a period of mobilization. Major facilities needed at the complex were:

- Projectile metal parts manufacture
- Grenade metal parts manufacture
- Load, assembly, and packing (LAP) for grenade and projectile
- Support facilities for all of the above.

A major point of contention was at what stage of the project contractor responsibility should begin. Three basic options came under discussion:

(1) Government designed, government built, contractor operated
(2) Government designed, contractor built, contractor operated
(3) Contractor designed, contractor built, contractor operated.

ARRADCOM representatives argued that the second option offered the best combination, providing design by a "disinterested" party with review and execution by the organization with ultimate responsibility. This approach was adopted and the Project Manager called upon the ARRADCOM Commodity Centers to supply all technical support for the endeavor.

A Bit of Euphoria for Those Involved

Before looking at the practical side of our efforts, we should point out that there was a great deal of emotion, exhilaration perhaps, involved in this effort. Imagine yourself in the position of the engineers at Picatinny and Frankford when they were selected to the ad-hoc groups created for this project! This was a rare, perhaps once in a lifetime opportunity—the chance to help create a viable plant literally out of a wilderness. Incredulity gave way to dedication as the realization grew that this was to be more than just another paper exercise; that, in the none-too-distant future, actual hardware would be delivered from the complex they had created. And everything—site plan, processing, gage lab, laundry, change houses, pollution abatement, etc.—had to be addressed.

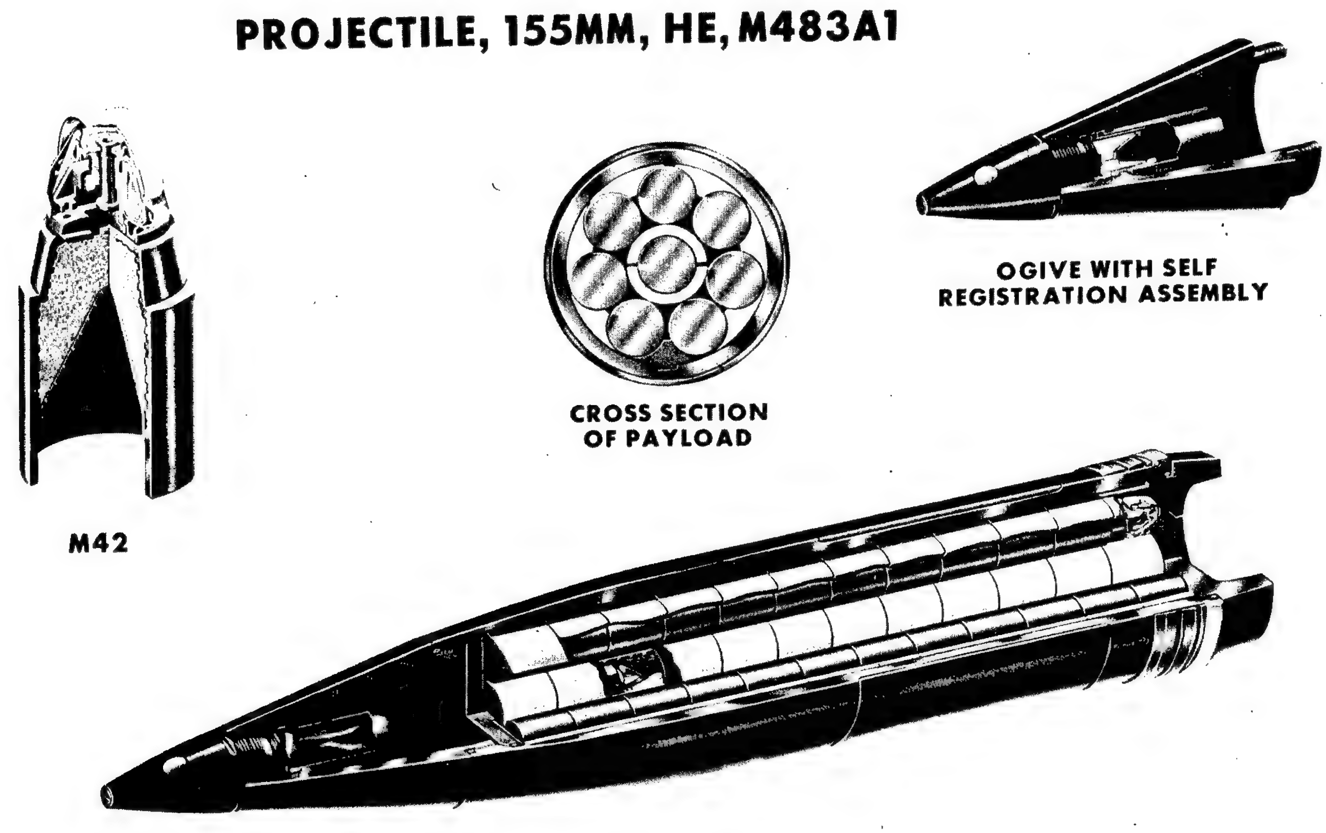


FIGURE 1

All those with a production background will envy the rare opportunity to develop an optimum process and then "house" it, instead of the usual necessity of shoe-horning some compromise process equipment into the constraints of an existing structure. There was a state of euphoria before the hard work began.

The work was hard, it was tedious, and sometimes contentious, but it was rewarding. Rather than present a step-by-step description of the process, we will hit some of the more significant high points in each of the major areas and show some of the novel approaches taken in the face of the large scale production that is called for.

The Product

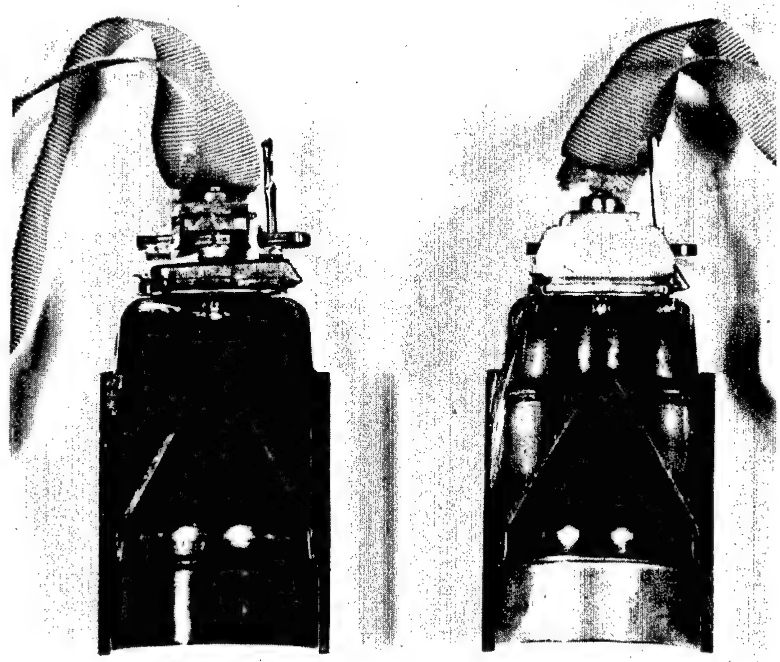
The M483A1 is a 155-mm projectile carrying some 88 submissiles (see Figure 1). Since the projectile acts only as the carrier for the grenades—it does not have to fragment. This basic functional difference from other artillery munitions predicated many design innovations, which, in turn, led to a more complex production process. The projectile has three components—ogive, body, and base—and utilizes three materials—steel, aluminum, and fiberglass.

The 88 grenades, carried in 11 layers, are ejected rearward by an expelling charge which is activated by a time fuze in the projectile nose. The grenade body (see Figure 2) is made of 4140 steel; an impact fuze is assembled to each grenade body. A detonator in the fuze ignites an RDX lead in the body, which in turn detonates the 1-ounce shaped charge of Composition A5. There are two types of grenades; the M42 for the first eight layers and the M46 for the last three layers. The inside of the M42 body is embossed prior to drawing. During setback, grenades in the last three layers cannot stand the loss in strength that embossing causes and therefore have a plain wall. An expelling charge in a polyethylene bag completes the projectile.

Plant Design Parameters

The specified production capacity of the plant is 120,000 projectiles per 500 hour month. To meet this quota, JCAP efficiency standards were used for plant design where historical data were not available. The plant was designed to be competitive and to be easily adaptable for peacetime operation at less than maximum rates. In this regard, the projectile forge lines and the final projectile assembly systems are the most costly. Fortunately, two of each are required, suggesting a peacetime rate of 20,000 rounds per month, which could be achieved by operating half the equipment on a single shift basis. The possibility of running with half the equipment in other production areas was considered as much as possible in the design process.

M42/M46 GRENADE WITH M223 FUZE



M42 **M46**

Another constraint was to operate within the state of the art so as not to jeopardize production capability. This did not mean we were limited only to facilities already used in M483A1 production, however. At that time, one manufacturer was producing projectiles; one had completed a production run of grenade metal parts and another was just coming on stream; and one Army Ammunition Plant had done all the loading and was gradually upgrading its equipment. It will soon become evident that, in some cases, the manufacturers had been locked into processes because of equipment they had available or which was provided by the government. They admitted that they might have taken other avenues had they had the wide open choices available to us. It was obvious, anyway, that a mere scaling up of the existing facilities would be indefensible. Thus selected operations were isolated early and efforts were initiated to find better ways of performing them. These were operations where high returns were feasible with little or no risk.

For instance, steel strips for the grenade metal parts formerly were embossed and then recoiled prior to blanking and drawing. These large coils were annealed in

beehive furnaces. The cycle was very long and approximately 40 percent of the material that eventually went to scrap was annealed needlessly. In addition, this operation was performed on a single width coil. By blanking a staggered double (or even triple) row right after embossing, and annealing the blanks only, a considerable reduction in scrap and an energy saving are effected.

Performance, Efficiency the Goal

Our initial task was to nail down the production process and to define the equipment required. ARRADCOM, where the entire project is now centralized in the Large Caliber Weapons Systems Laboratory, had not yet been established. The work was, therefore, carried out by two organizations. Projectile production was assigned to Frankford Arsenal and cargo and load, assemble, and pack operations to Picatinny Arsenal. Their efforts were coordinated with both teams applying the same philosophy—high degree of automation, automatic inspection, performance specification for procurement of equipment, etc.—but detailed results were necessarily of a different nature. For example, the net output of the projectile plant is 240 high value items per hour; the cargo plant has to spew forth 21,000 parts per hour. Obviously, different approaches to materials handling, quality control, and banking between operations were required. Thus each plant is discussed separately.

Projectile Metal Parts Plant

The projectile body will be produced by the familiar hot forge, heat treat, and machine process. This process offers great flexibility and has been proven in the manufacture of many artillery projectiles, the M483A1 included. Many phases of the existing process were modified, however.

Steel billets are generally separated into individual segments prior to heating and forging by the "nick and break" technique. Less commonly used methods are sawing, flame cutting, and cold shearing. All of these processes either leave irregular parted surfaces or waste energy. A new system now finding use in commercial forging is the "hot shear system" in which steel billets are heated to 2100 F in an electric induction furnace and then parted in a shear press prior to forging. Following an MM&T evaluation project, the hot shear system was adopted for the new plant.

Anticipation Planning

Where known improvements were in the wings but not yet "state of the art", we had to plan for initial use of the known process. Nevertheless, care was taken to ensure that the improved method would fit into the specified space and utilities envelope if and when it proved successful. An example of this approach is the process for applying the rotating band. This operation has always caused problems in M483A1 production because the thin section of the body under the rotating band precludes the use of the conventional swaged on copper band blank. During the R&D phase of the program, a deposited copper overlay band process, using a shallow rotating band seat, was developed. This process had been used for 7 years in production and was baselined for the new facility to establish building parameters and cost estimates. Now we are seeking eventual savings in space, utilities, and costs through a two pronged approach:

- An MM&T project to investigate inertia welding for this item
- A study to increase the rate of depositing copper on the steel.

Results of these efforts should be available before equipment has to be purchased. Current plans allow integration of either method.

More Machines Than Operators

Projectile production equipment will be procured to meet functional descriptions, which cite both production quotas and what the operation must accomplish. All production equipment will be automatic in that human assistance will not be required throughout the entire machine cycle from the loading of one piece to the loading of the next. Operators will be required—one for several machines—to monitor the operation and to make tool adjustments and changes when necessary.

With a large number of individual operations, the material handling system connecting individual machines and operations must provide for minibanks to absorb the continuous variations in the flow of components from point to point. These variations result from the variable efficiencies of individual production machines. In addition, first in, first out banks are provided at three strategic points to absorb major production fluctuations.

Considerable innovation has been applied to inspection in the projectile plant. In the past, dimensions have been sampled by hand for both process control and final acceptance. This procedure does not lend itself to the M483A1 production rates and the number of dimensions that require checking. The new facility will provide 100 percent automatic gaging of all significant dimensions immediately after the dimension is established. At first glance, this approach may seem to be a step backward from sampling. However, 100 percent automatic systems can keep

pace with production operations, eliminate human judgment, and be cost effective. By inspecting 100 percent, we can spot trends in machining operations caused by tool wear and breakage and can signal the operator monitoring the operation when the dimension in question is approaching a preset limit. Automatic gaging can be done while the next piece is being machined so that no scrap is produced.

Before this concept is implemented, the end item specification will have to be rewritten around 100 percent automatic inspection. The idea of "final inspection" as it is practiced today, will have to be changed. With 100 percent automatic inspection, each dimension will be finally accepted when the last operation is performed on it.

Cargo Metal Parts Plant

Cargo metal parts production is generally a lighter type of operation than projectile production. Thus, there was an even wider choice of methods and of specific equipment. In order to provide the Corps of Engineers with the required production parameters—such as area, weight, and utilities required—industry and government sources were surveyed operation by operation to find the equipment best suited for each. These specific types and models were then used to establish working areas and other required parameters.

In order to maintain competitive procurement, all specifications were clearly understood to be tentative. The equipment specifications then were written purely on a performance basis: "This is the part we are handing you (sketch) ... this is the part the way we want it back from you (sketch) ... this is the total area available to you." Obviously, there are modifications to these basic requirements; for instance, it is stated that the required staffing will be a factor in the evaluation of bids as will such items as utilities usage, cost of associated materials handling and pollution abatement measures. Each specification also contains a mandatory minimum number of machines per bank so that availability will not be degraded. Bidders are asked to assign their own availability values which they will be expected to demonstrate prior to final acceptance. They are also encouraged to bid based on a number of different hourly production rates so that the procurement can be "fine tuned" after receipt of the bids. The reliability, availability, and maintainability (RAM) requirements are written to encourage maximum mean time between failure and minimum mean time to repair.*A RAM analysis will be conducted after receipt of the bids to choose the best possible piece of equipment for each and every operation.

*MTBF is mean time between failure and MTTR is mean time to repair.

"Collector" Concept Applied

Designing the materials handling system for the cargo metal parts plant was another complex problem. Roughly 30,000 parts per hour will pass through more than 26 process and inspection steps, each performed by multiple machines. For purposes of designing this system, we decided that all machines performing a particular operation will discharge their product to a common "collector" after process controls verified quality. Most likely this collector will be an overhead conveyor with enough dynamic storage capacity to act as a buffer. The collector will then become a supplier to feed, on demand, any of the machines in the succeeding "bank". No one on one relationships, which are murder on efficiency, are allowed. Computer work is continuing to size this system so that the conveyor buffers even out production vagaries.

Item specifications came under scrutiny as well in considering materials handling. Based on Mil STD 105 principles, parts must be held until representative samples qualify a given quantity. Obviously, 30,000 items per hour cannot easily be removed from the flow, held, and then returned to the line. Clearly, a new way had to be found.

Inspection Compromise Practical

Special specifications were developed for high volume production. Initial thinking was that 100 percent automatic inspection "on the fly" after each operation would prove economical—weighing rejection of parts which might have passed ordinarily against the cost of sampling under the aforementioned conditions. With this went the idea of testing each machine's output before it joined the stream from the other machines in the same bank so that pollution could be avoided. But, with approximately 300 machines on the floor, the proliferation of inspection equipment and personnel would have been intolerable.

Consequently, we now call for a final inspection area in which we automatically check all parts for 18 defects. Process controls upstream will act as valves releasing only material of sufficient quality to insure maximum overall economy. The grenade specifications have been tailored accordingly; they do not compromise the quality of material procured to the "old" specification, but offer a more palatable means to the same end for the special case of such large scale production.

Load, Assemble, and Pack Plant

The LAP plant is, of course, the most complex of the areas. Here we are not only dealing with equipment decisions, but with the site plan as well, involving many buildings. For a change, safety engineers had the chance to

jockey buildings around on paper during the planning stages instead of processing endless waivers; trade-offs were possible between explosive allowances, and construction features and walls could be hardened according to need. Each deliberation led to a fascinating round robin between process, materials handling cost, and construction cost.

Survivability Considered

One of the most carefully studied characteristics of the entire complex was the survivability of the "heart" of the LAP area. There are three elements here: the grenade loading area, the grenade assembly area, and the projectile assembly area. The current producer operates essentially in three separate buildings; this became known as the "three building concept" (see Figure 3, top). It was suggested that the three elements could be made in a single building, the operations adjoining end to end. Safety required that each area be protected from its neighbor(s) (see Figure 3, middle); this became known as the "one building concept". An explosive incident here, however, would put the entire plant out of commission. This fact gave rise to the "two building concept" (see Figure 3, bottom), which splits the single building into two redundant, but smaller, buildings. Two totally independent lines are thus established with inherent 50 percent survivability. This offers the additional benefit that at peacetime rates one of the lines can be held in standby. After long deliberation, the additional $4.5 million cost for the two building concept was adjudged to be warranted.

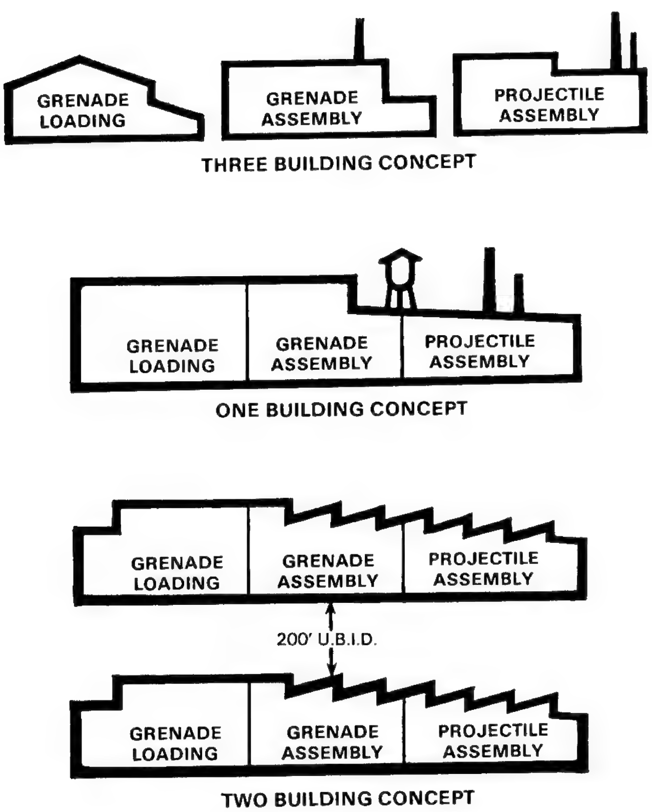


FIGURE 3

Variable Timing of Assembly Feasible

The LAP area offers another major illustration of adapting to higher production rates and attaining greater flexibility without endangering success. The assembly of the grenade layers into the projectile is currently performed "serially". The projectile, on a pallet, is brought by conveyor to a press operator. He inserts the eight grenades and associated hardware, seats the "layer" in the press, and signals the pallet to advance. The process is then repeated. There are 12 of these stations (11 grenade layers and one layer of "adapters"). The entire system is thus controlled by the slowest operator. In addition, 12 operators are needed even at lower production rates. To circumvent these shortcomings, we developed the concept shown in Figure 4. Operators at the first ten stations each insert eight layers of M42 grenades; operators at the last five stations each insert three layers of M46 grenades and one layer of adapters. Each operator works at his own pace (but his daily output is counted automatically) and dispatches his shells to join the stream. At lower production rates, fewer stations are used. A computer analysis has confirmed feasibility of the timing throughout this system. The assembly of multiple layers also eliminates some transfer time.

Another problem in assembly has not yet been solved, but we are working on it. Obviously, manual assembly of the layers right at the pressing stations is too crude and wasteful to be compatible with the higher production rates. However, no automated equipment has been designed—much less proven out—that we could confidently specify. Two MM&T projects are now in progress to automate both the layer forming and the assembly of such machine-made layers to the projectiles.

Current Status

Late in 1976, an operating contract was awarded to construct the complex and carry it through to the operations phase. The documentation showing processes

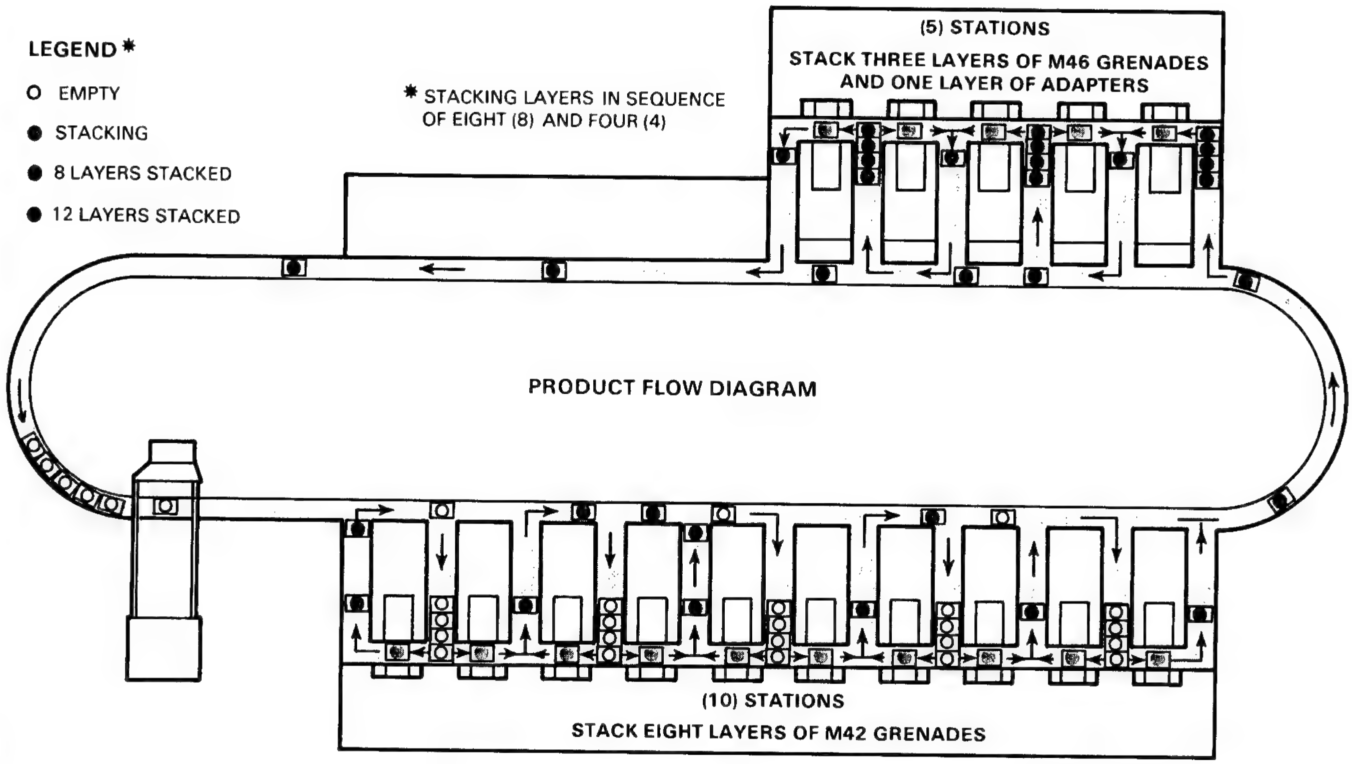


FIGURE 4

and layouts with sample equipment, safety site plans, item and production equipment specifications, and many lesser supporting items has been turned over to the contractor. At meeting after meeting, ARRADCOM representatives have been explaining and justifying their decisions; they have lent their support where the contractor suggested improvements. Mutual respect has prevailed throughout these discussions, to the Army's benefit, and it is hoped that the strong relationship will continue. ARRADCOM engineers can make a significant, continuing contribution in the traditional checks and balances inherent in the translation of paperwork to a functioning plant.

Lesson Learned

We have been amazed at how much information is around for the asking within the government. Quality Assurance and Manufacturing Technology experts assisted, of course, in every phase; but untold numbers of specialists surfaced who contributed their expertise. The friendly cooperation of many commercial concerns provided access to important detailed information.

Through review after review by government and industry consultants, the process developed in house by ARRADCOM remained virtually unchanged—even now with the operating contractor scrutinizing every line drawing to make certain that he can "make it work". ARRADCOM engineers did their homework well and left nothing to chance. How often we have seen faces that are new to the project light up in recent weeks with "new" ideas—and had to tell them that we had probed the same approach and why we had discarded it.

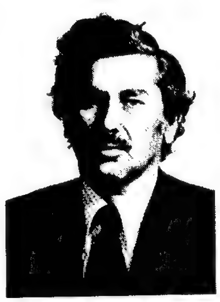
Although this same team will probably never again be involved in another of these dream projects, we hope that the Army will look back on our effort when the time comes and again opt for "Government designed, Contractor built, Contractor operated".

Automated Equipment Reduces Costs, Hazards

Improved Handling at

VINCENT J. GRASSO is also a mechanical engineer in the Large Caliber Weapon Systems Laboratory with 13 years of experience in the Army ammunition field. The majority of this work has been in the capacity of production engineer on several fuze programs. He has also participated as a team member on some material handling investigations. Mr. Grasso served as assistant to the project officer on the depalletization and carton opening program.

LAWRENCE H. WEINER is a mechanical engineer in the Large Caliber Weapon Systems Laboratory of ARRADCOM. He has 14 years of experience in the field of automated equipment design involving the production of ammunition items. His background includes production engineering and product design experience. Mr. Weiner served as the project contract officer for the depalletization and carton opening program.



New automated material handling procedures at the Kansas Army Ammunition Plant (KAAP) provide significant reductions in transportation and handling costs. ARRADCOM engineers have developed improved methods for transporting incoming cartons of mortar shells and for opening them and removing the shells. The system drastically reduces operator exposure to hazardous handling operations and allows more efficient operations and reduced manpower at the KAAP melt-pour facility.

The equipment can handle a variety of pallet sizes so that future needs for the same type of equipment can be met without redesign. In addition, it provides a readiness capability for handling mobilization rates of production of the 60-mm and 81-mm shells it is designed to handle.

The innovative facility is part of the overall modernization of the load, assemble, and packout (LAP) plant at KAAP. As part of this modernization program, a new explosive melt-pour facility is planned, and an automated assembly line has already been built and installed. The plant will be geared to high production rates. Thus, automation was required of manual operations still performed in the system. A particular need was for depalletization and carton opening equipment that could keep pace with the production facility.

The shells arrive at the LAP facility in large cartons (holding twelve 81-mm shells or twenty 60-mm shells) stacked on pallets (see Figure 1). With the new system, the pallets are delivered to a conveyor by a forklift and an operator removes the straps and battens. From there, the unpacking operation is completely automated until individual shells reach the load operator.

Handling Reviewed Thoroughly

The development effort began with a thorough review of metal parts handling, including procedures at the metal parts manufacturer. Only the 81-mm mortar was in production at the time of review. After producing the mortar projectile bodies, the manufacturer placed them in corrugated cartons. The cartons were placed onto pallets and shipped to the LAP facility by either truck or freight car. The pallet was not shipped with the cartons.

The procedure was merely reversed at the LAP facility. Empty pallets were brought to the carrier and the cartons

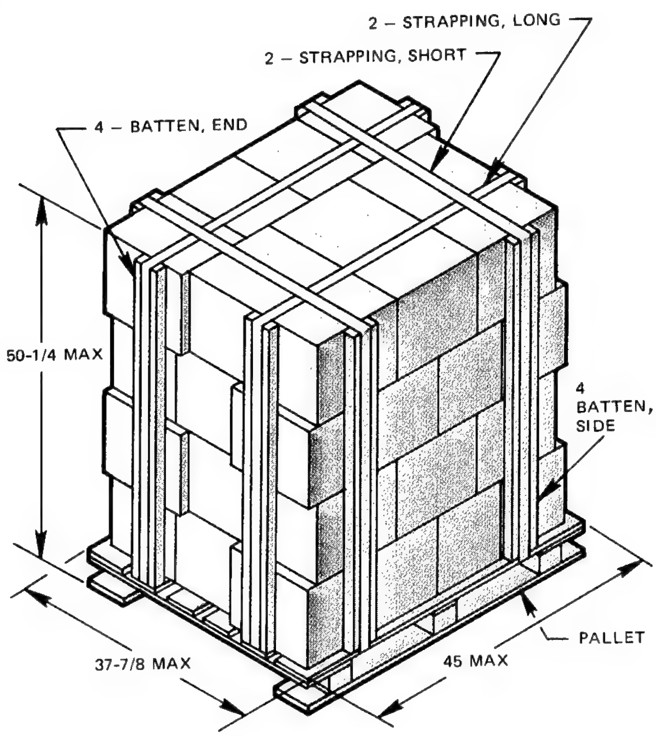


FIGURE 1

Mortar Loading Plant

were loaded onto the pallets. The loaded pallets were delivered either to the production area for immediate use, or, more likely, to a holding area. The repeated handling damaged both the cartons and the contents.

When the pallets arrived at the production line, an operator would remove the cartons and place them on work tables. Other operators, using a knife or razor blade, would open the cartons manually and remove the projectiles. The operator had to orient each projectile in the nose down position because they had been placed in the cartons without regard to position. An operator also had to dispose of the empty cartons. The handling and packing method obviously created unnecessary labor costs. Thus, a uniform and economical method of shipment became an important part of the automatic depalletization and carton opening development.

New Procedures Overcome Problems

As a first step in devising a method of shipment, ARRADCOM developed a standard 36 in. by 44 in. pallet. This was selected as the optimum size for both load carrying and space utilization purposes. Any other size pallet would not fully utilize the available space in either freight cars or trucks. With the pallet size selected, optimum carton size was also studied. The maximum pallet load was limited to 2500 lb to allow the use of existing forklift trucks in the LAP plant. For the 81-mm projectile, a carton weighing under 65 pounds and holding 12 projectiles (3 x 4 configuration) was selected. The 60-mm projectile, being lighter, was packed in a 4 x 5 configuration, the carton weighing less than 45 pounds. The weight of the carton was critical because the metal parts manufacturer might still utilize manual loading. Also, should automated equipment at the LAP facility break down, manual handling could be used temporarily.

It was also obvious that repeatedly loading and unloading the cartons was undesirable. A study clearly showed the economic advantage of shipping the cartons on the pallets and the initial cost of the necessary supply of pallets was approved. As a final measure to ensure compatibility with production line requirements, packing of the projectile "nose end down" was required and the cartons were marked so that they could be stacked on the pallet in the proper orientation.

Survey Reveals Equipment Need

With the palletized carton system approved, the design of equipment to depalletize the cartons, open them, and remove the contents automatically began in earnest. Original plans called for the purchase and integration of standard depalletization and carton opening equipment. However, a survey of equipment manufacturers revealed that the available standard "off the shelf" equipment was unsuitable for this application. Load handling capacity was below requirements and the equipment did not meet the explosion proof requirements for installation at the LAP facility.

Standard carton depalletizers, such as those found in the food processing industry for handling bottles or tin cans, were only capable of handling carton loads up to 25 pounds. In addition, falling cartons, which would require operator attendance, were observed frequently. Discussions with the equipment manufacturers disclosed that modifications to allow handling of 65 pound cartons would cost more than development of a new piece of equipment. Furthermore, because of the basic design of the available equipment, modification for a heavier load capacity did not guarantee that the equipment would be able to handle the 65 pound load.

The need for explosion proof motors and controls presented another problem. Finally, the survey showed that available box opening and separation equipment could not carry sufficient loads. Therefore, Innova, Inc., of Clearwater, Florida, was awarded a contract to design and fabricate special handling equipment in accordance with the government's specification.

Specific Needs Met

Operation of the newly designed system is shown in Figure 2. The palletized cartons are delivered to an input conveyor by forklift. An operator removes the pallet strap and batten and pushes an indexing switch to move the loaded pallet to the next station. A strap detector on the input conveyor assures that only pallets with the strap removed are moved into the depalletizer. The pallet infeed conveyor has space for three pallets.

The depalletizer consists of a hydraulic lift table and a clamp mechanism that automatically unstacks one layer of cartons at a time, placing the cartons onto a separation conveyor. The unit is adjustable for pallets 36 through 48 inches long and 36 inches wide. Adjustments are provided for carton heights of 4 through 12 inches. After the last layer of cartons is removed, the empty pallet is transported by conveyor to an empty pallet magazine for storage. Stacks of empty pallets are periodically removed by forklift. A top layer carton removal device was selected to minimize the problem of falling cartons caused by the bottom layer removal method.

The separation conveyor is a series of roller conveyors moving at progressively increasing speeds. Here, the layer

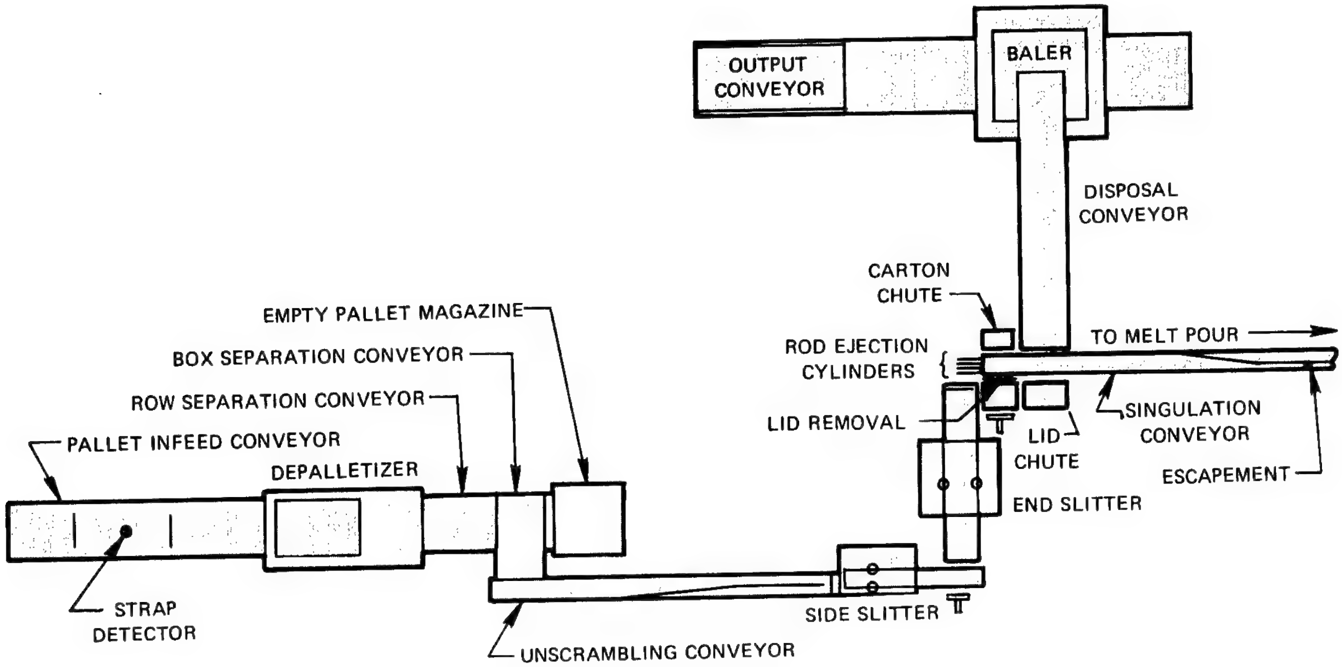


FIGURE 2

of cartons is separated into rows and the rows fed onto an unscrambling conveyor where the cartons are spaced. Devices along the conveyor properly align the cartons for the slitters.

Dust Hazard Overcome

In the slitting area, the cartons pass through two pairs of blades that cut all four sides of the cartons at the base. Knife edge blades are used to minimize unnecessary dust that would be generated by saw blades. A vacuum system was incorporated to prevent dust from spreading to the surrounding area. (Airborne dust is hazardous in explosive areas and could contaminate the inside of the mortar shell, preventing a successful explosive pour.) The carton slitters are designed to accept cartons 8½ through 14 inches wide.

After slitting, the carton is positioned against a lid removal unit. The carton and contents are pushed off the bottom lid onto an adjacent conveyor. The lid is pushed into a disposal chute by the next carton brought into position. The carton moves to the carton removal station and is lifted from the shells, together with a corrugated divider that separates and protects the mortar bodies during transportation. An inclined conveyor removes both items for disposal.

The rows of shells are successively pushed onto a separation conveyor consisting of a series of sections moving at progressively higher speeds. The shells, nose end down, are brought to an escapement which releases one shell at a time at a predetermined delivery rate. A control system built into the equipment sequentially shuts down the various operating elements whenever the output of the system exceeds the production demand.

The empty carton sections, dividers, and the bottoms of the cartons are brought by conveyor to a baler, the one major component available "off the shelf". The bale is automatically formed and a signal notifies the operator when it is completed. Since production requirements did not justify equipment for automatic wiring of the bale, an operator does this manually, an operation that takes about 5 minutes. The finished bales are automatically ejected from the baler and deposited onto an output conveyor for removal by forklift.

Equipment for Future Needs

The depalletization and carton opening equipment was developed specifically to handle the 81- and 60-mm mortar rounds at a delivery rate of 44 parts per minute. The equipment has specific settings for handling the carton sizes for these rounds. However, by providing adjustable machine features, various carton lengths (10 through 22 inches), widths (8½ through 14 inches), and heights (4 through 12 inches) can be accommodated. As previously mentioned, pallet lengths of 36 through 48 inches are accepted, while pallet width is fixed at 36 inches. A unit capable of handling other widths could be provided.

This versatility means that future demands for this type of equipment can be met without additional design activity. With this equipment, ARRADCOM is prepared to meet the mobilization rates for 81-mm and 60-mm mortar production.

An End To Process Development Woes?

New Pilot Plant Features Computer Simulation

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Pity the poor process or manufacturing engineer saddled with turning a touchy, complicated laboratory procedure into a polished, efficient process for full scale production. Anyone in manufacturing knows what a hair pulling ordeal this can be—not to mention how time consuming and costly. The manufacture of explosives is no exception—it might even lead the way in hair pulling. Certainly, engineers at ARRADCOM (though they may not yet be bald) will attest to the tribulations of developing manufacturing processes for explosives.

Well, their most difficult trials may be at an end. ARRADCOM is now installing an exciting new pilot plant at Dover, New Jersey, to bridge the broad gap between the laboratory and production processes. This unusual and versatile plant, utilizing computer simulation, will be suitable for every kind of explosives production development. By easing the transition from lab to plant, it should reduce both costs and time in instituting new processes. This can be particularly critical in a mobilization situation. In addition, it will encourage process improvements that manufacturers would have hesitated to introduce in the past because of the risks involved in trying something unproven.

The pilot plant will feature a remote laboratory control building for safe computer control of explosive processing. Initial process development will be directed toward TNT nitration and HMX/RDX nitrolysis. A single multistory building will house facilities for both processes. Utility banks will provide the ability to arrange equipment as it is needed.

The facility will utilize ARRADCOM's extensive computer capabilities for both process control and simulation of the TNT nitration operations. Oriented toward future process improvements, the pilot plant will differ from production plants (which also differ among themselves) in some important aspects—for example, digital control and dynamic separators. As new processes are developed through pilot operations, these production plants will be changed to meet the needs.

Computer Control

ARRADCOM is not basing its confidence in smoother, more efficient transition from lab to production merely on having a new pilot plant, however. The important point is how that plant will operate. The ARRADCOM pilot plant will be remotely controlled by a computer based system. As many as 80 control loops can be implemented either in the standard analog mode or in the direct digital control (DDC) mode, with the further option of computer set point control. Sequential functions such as those involved in startup and shutdown can be handled automatically by programmable controllers. Personnel exposure to the process building itself will be limited to only periodic sample taking and product removal.

Without computer simulation via mathematical models adapted to each production or pilot process, transition would be an extremely difficult trial and error procedure, as it has been in the past. A simple scale-up

would not work well because of the inherent process differences already mentioned. In addition to smoother transition from pilot plant to production line, computer simulation will shorten the procedure of optimizing process conditions, such as acid composition in the pilot plant. Finally, ARRADCOM's use of computer simulation will greatly facilitate the translation of beneficial process developments from one production facility to another. Thus, the new pilot plant will offer several important advantages. Specifically, how might it affect development of the two processes for which it was initially designed?

The Continuous TNT Process

The continuous TNT process was introduced to the United States less than 10 years ago. Existing batch TNT facilities at that time were of World War II vintage. The Canadian Industries, Ltd. continuous process design has been scaled up to completely modernize those facilities. Almost from the start of continuous TNT operations in 1968 in Radford, Virginia, it was recognized that process improvements were needed. These improvements at first were aimed primarily at pollution abatement, which was always a matter of concern but is now a matter of urgency. The pollution problem originates in the initial nitration part of the continuous process.

Figure 1 depicts the nitration portion of the existing process. There are six countercurrent nitration stages. Two of these have extra nitrators in series for cooling purposes,

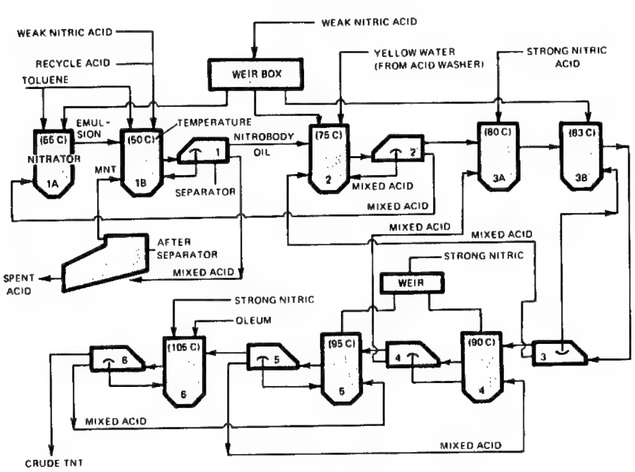


FIGURE 1

resulting in eight nitrators. After each nitration stage, the acid phase settles out in a gravity-type separator, and flows back to its originating nitrator as an internal recycle for cooling purposes (the separators have no cooling coils). It also flows to the preceding nitration stage as part of the countercurrent scheme. The supernatant organic phase in the separator flows to the next nitration stage. Toluene and weak nitric acid (60 percent) are introduced in the early stages and strong nitric acid along with oleum are added to the last nitration stages.

Major efforts to control pollutants in the continuous TNT process have concentrated on the unwanted formation of unsymmetrical TNT during nitration. Unsymmetrical isomers comprise about 4 percent of TNT. Together with other impurities in the final product, they cause exudation of TNT during storage, particularly at elevated temperatures. Therefore, it is necessary to remove these isomers by purification. The purification process, however, results in large volumes of red water, which carries off the soluble sulfonates of the unsymmetrical isomers together with some product loss of soluble alpha-TNT, constituting a major pollution problem.

Low-Temperature TNT Process

Stanford Research Institute developed a low-temperature TNT process which provided a step toward eliminating the red water and improving yield by reducing meta-isomer formation to an acceptable level. This low-temperature process, shown in Figure 2, has only two

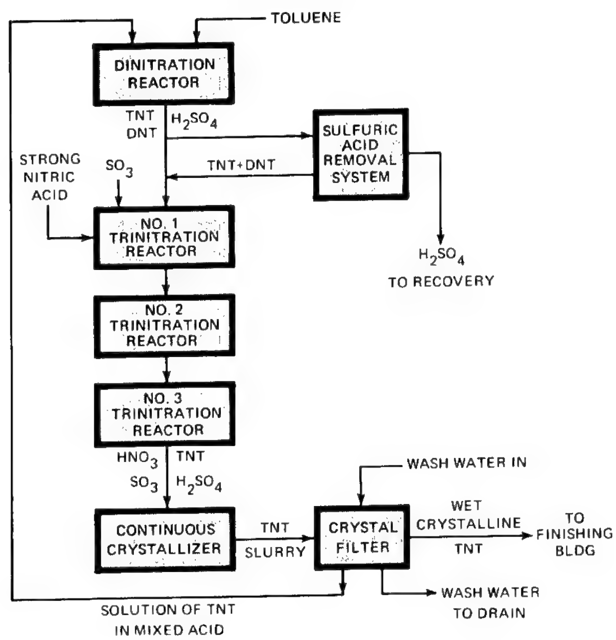


FIGURE 2

stages compared with the six nitration stages of the continuous process. It requires lower temperatures, especially in the first nitration step, and uses anhydrous conditions throughout. A single acid phase (no organic phase) is maintained by a sufficient acid-to-nitrobody ratio.

In the first low-temperature nitration step, dinitration is almost instantaneous under the anhydrous acid conditions and the amount of meta-isomer produced drops from the usual 4 percent to about 2 percent. Although there is still sufficient unsymmetrical TNT to require purification, this purification is obtained through a selective crystallization after trinitration. The ARRADCOM pilot plant was originally designed around this entirely new process. Because of costs, however, it was decided to

shelve the low-temperature process in favor of improving the continuous process.

During the development of the low-temperature process, it became apparent that even limited adaptation of its principles could provide improved performance with comparatively minor changes in existing equipment and operating conditions. For example, reducing the mononitration temperature in nitrators 1a and 1b from 50 C to 20 C significantly reduces the amount of meta-isomer formed, even though other nitration conditions remain unchanged.

Explosion Spurs Development

The need for TNT process improvement was emphasized in May 1974 when a TNT explosion at Radford AAP destroyed the nitration and purification building of a continuous TNT line and knocked out the other two TNT lines as well. An investigation of this incident revealed that certain aspects of the process were far more hazardous than had been suspected. Many changes were recommended immediately for the restoration of the damaged lines. Some problems, such as white compound formation, require further study.

White compound is believed to be formed directly or indirectly from trinitrobenzyl alcohol and trinitrobenzaldehyde oxidation products. If these precursors can be oxidized preferentially to trinitrobenzoic acid, white compound formation can be avoided. Otherwise, when the precursors, which are formed in concentrated acid, come in contact with less concentrated acid, white compound is formed. This is what normally occurred in Nitrator 2 at Radford, where the compound coated cooling coils and other surfaces, thereby necessitating periodic cleanout in order to restore adequate heat transfer and fluid flow. It was during such a cleanout operation that the Radford explosion occurred.

Probably, a suitable rearrangement of nitrator temperatures and acidity values will curtail white compound formation. Also, better phase separation between nitration stages will reduce the entrainment of the organic precursors in carry-back acid to less acidic nitrators.

Dynamic Separators To Improve Efficiency

More efficient phase separation between stages will be implemented by the replacement of gravity type separators with dynamic (centrifugal) separators. These separators are to be used at Radford, however, for a more pressing reason.

A major finding of the Radford explosion investigation was that the quantity of in-process detonable material in the nitration section of the TNT line was much greater than was supposed. This was primarily because of a mistaken assumption that nitrobody dissolved in the acid phase was not detonable. The amount of nitrobody in each nitrator may be reduced by increasing the internal recycle of acid from the separator back to the nitrator. This requires dynamic rather than gravity-type separators; the latter cannot greatly increase their throughput without introducing an entrainment problem, especially at those stages where the phase densities are similar. However, the dynamic separators have one side effect. They reduce the time that the nitrobody is exposed to nitrating conditions. It is expected that nitration temperatures will have to be raised to compensate for the decreased residence time. Other effects on strong acid feed rates and oxidation will also be studied in the pilot plant.

Other Improvements Sought

The ARRADCOM pilot plant will be dealing with other problems such as reducing consumption of strong acid and the external dilution of spent acid from the first nitration stage. These problems represent potential process improvements that must be optimized in conjunction with the improvements already mentioned. Considerable improvements in yield, safety, pollution abatement, and cost reduction are indicated. All of these initial improvements are concerned only with nitration. Subsequent engineering work on the purification section will require installation of additional equipment in the pilot plant.

The nitration portion of the pilot plant is illustrated in Figure 3. In the mononitration stage, a special tube and shell type of reactor will permit close control and monitoring of temperature for reducing the meta-isomer formation. Dynamic separators will be installed in the pilot plant to check out and optimize the changed process conditions for these new units scheduled to be installed on the restored TNT lines at Radford.

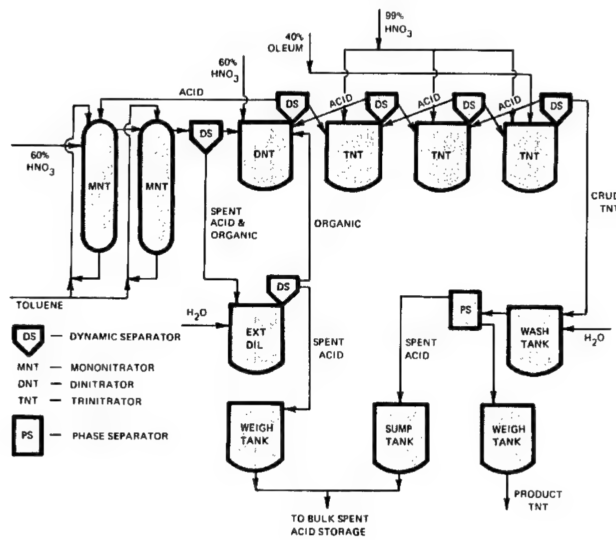


FIGURE 3

Pilot Plant Mathematical Models

During the design of the TNT pilot plant, questions arose concerning plant start-up. Development of a dynamic model appeared to be an ideal way to answer

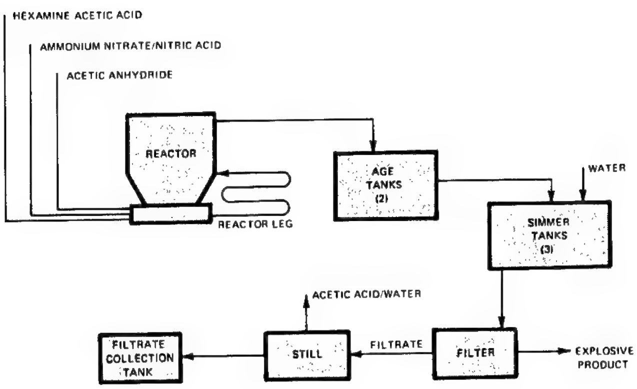


FIGURE 4

these questions, as well as determine dynamics of the pilot operation in order to estimate acid sampling periods and critical points for sampling and control. Additionally, the model could provide a useful format for data logging and correlation during pilot plant operation. Longer range plans included the possible use of the model in on-line control strategies.

A simplistic, building-block approach was used in developing the model. At each vessel a material balance was written for each of the chemical components, resulting in a system of 12 first order, ordinary differential equations. These were coupled through component composition terms. The transient solution was arrived at by numerically integrating these equations for each vessel in succession. A simple Euler's algorithm was used to give rapid, stable solutions on the CDC 6600. The material generation terms within the material balance equation were based on fundamental nitration kinetics and mixed acid equilibria. Dependence on empirical correlation was kept to a minimum, restricted primarily to the area of solubility data. For optimization of process operating conditions, a static model was adapted from the one prepared for production TNT lines.

The HMX/RDX Process

The other process slated for initial pilot plant development is the HMX/RDX process.

The Holston Army Ammunition Plant is the only production plant in the U.S. for the manufacture of RDX and HMX. It is limited to a non-systematic scale up from laboratory to production prove-out for process improvement studies on RDX and HMX nitrolysis. The ARRADCOM pilot facility will be capable of producing 20 lb/hr RDX on a continuous basis, as well as operating batchwise (5-lb high-explosive batches).

The Bachmann Process currently utilized at Holston AAP for the manufacture of both RDX and HMX uses hexamine, acetic anhydride, acetic acid, nitric acid and ammonium nitrate as the basic raw materials. Projected mobilization requirements for RDX are very high with the HMX requirement forecast at about 1 percent of the RDX total. The HMX process requires large excesses of raw materials and yields are low compared to the RDX process. This results in a cost for HMX approximately five times that of RDX. Improvements in the efficiencies of these processes would result in significant cost savings and reductions in raw materials consumed and could make HMX an economically more attractive explosive to the munitions designer.

Complex reactions are involved in the formation of both compounds and the mechanisms are not completely understood; nor have all of the intermediates been identified.

However, by manipulating feed rates, temperature, concentration, etc. the main product formed can either be RDX or HMX. Although several studies were conducted in the past to maximize yield for RDX and HMX, these have not been completed, and for the most part were performed on a laboratory scale.

Successful laboratory work was sometimes implemented in production. But, since this scale up from laboratory to production is not always productive, the explosive manufacturer is always somewhat apprehensive about taking the risk. The pilot facility will make it possible to reduce the risk to the manufacturer instituting process improvements in production.

The Bachmann process forms many different products that can be considered intermediates for RDX and HMX or by-products that are mostly decomposed during the simmering operation. A simplified schematic of the ARRADCOM pilot processes is shown in Figures 4 and 5.

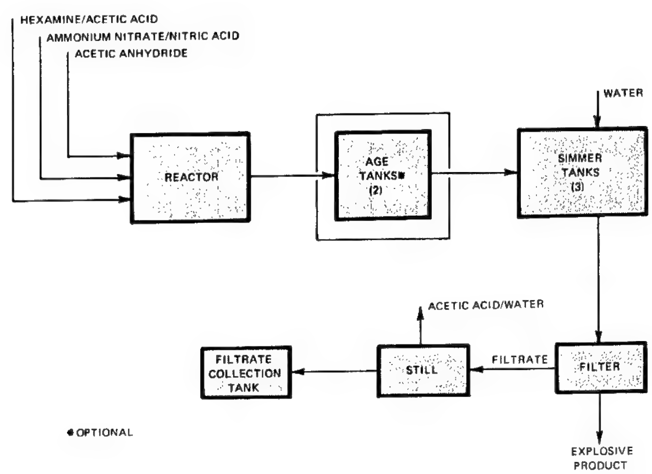


FIGURE 5

In the process improvement studies at the ARRADCOM pilot plant, the latest laboratory and computer technology will be fully utilized.

The TNT and HMX/RDX pilot plants are housed in the same buildings at ARRADCOM's Dover site and the same extensive laboratory facilities, remote control capability, automatic controllers, and computer are available for needed support of current and future programs.

Ammunition Lead Time Slashed

Computer Aid Makes It Possible

STANLEY S. HART is a Project Engineer in the Technical Support Directorate at the U.S. Army Armaments Research and Development Command, (ARRADCOM), Dover, N.J. He received his Industrial Engineering training at the University of Pennsylvania and his Industrial Statistics training at the School of Business Administration of Temple University. In 1969, Mr. Hart completed the graduate level "National Security Management" program with honors at the Industrial College of the Armed Forces. With the Department of the Army since 1962, he has supervised numerous manufacturing engineering activities, and over the past 7 years he has managed projects in Computer Aided Design/Manufacturing (CAD/CAM), Interactive Graphics, Numerical Control, and Group Technology. He is an active member of the CAD/CAM Committee of the DOD Manufacturing Technology Advisory Group (MTAG) and also is a Fellow of the American Society for Quality Control (ASQC).

Through programs now under way, ARRADCOM is developing computer aided manufacturing systems for large caliber ammunition. The goal is to significantly reduce the long lead times that have been an inseparable part of buildup to mobilization requirements, and at the same time reduce costs. The overall project is labelled TRACIM—Technical Readiness Acceleration through Computer Integrated Manufacturing. It is being conducted by the Experimental Fabrication Division of ARRADCOM's Technical Support Directorate.

Using computer hardware already operating on other programs, TRACIM is being applied to the production of two shells—a 155-mm round and a 105-mm round—while developing and implementing both computer aided design (CAD) and computer aided manufacturing (CAM) systems. Based on the experience gained, ARRADCOM will be able to prepare documentation and instructions for similar programs at other ammunition plants. Much of the development should also be applicable to other manufacturing processes involving such items as small caliber ammunition, fuzes, fire control instruments, and weapons.

Long Lead Time Required in Past

The Army has long recognized that the lead time required to build up ammunition production (PEP) lines to scheduled mobilization requirements is unnecessarily long. Until a sufficient level of computer technology (including graphic displays) was developed, however, there appeared to be no practical answer to this problem.

The Vietnam buildup period certainly provided ample testimony to the magnitude of the problem. Figure 1, for example, describes the production buildup of 105-mm ammunition at a particular contractor plant during that time. Although this was an accelerated, high priority effort, it took about 16 months to meet scheduled production. When buildup orders came in April 1966, the plant was producing 34,500 shells per month using one of six production lines in place. The mobilization schedule called for one million shells per month. Actually, it was 23 months from go ahead until the required schedule was met, including planned plateaus that totaled approximately 7 months. It took 16 months of production acceleration in addition to the plateau periods to reach the million per month goal.

Stockpiling has been considered as a possible solution to the problem. However, costs are estimated at over a half billion dollars for material and semifinished parts alone. Other costs would include storage, loss due to obsolescence and engineering changes, and administrative changes. Furthermore, stockpiling would probably reduce lead time by only 3 to 4 months. Thus, other solutions were sought.

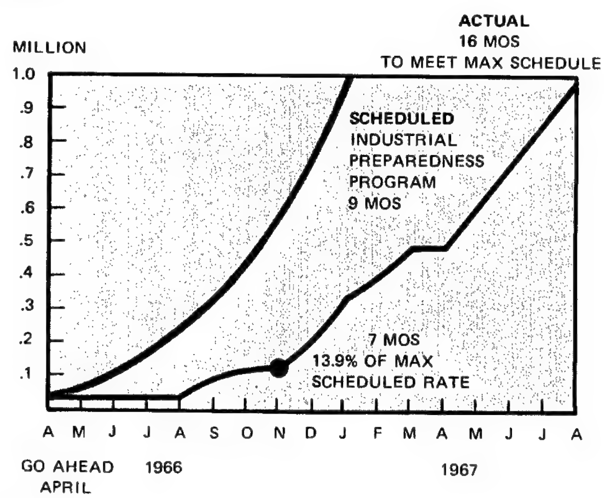


FIGURE 1

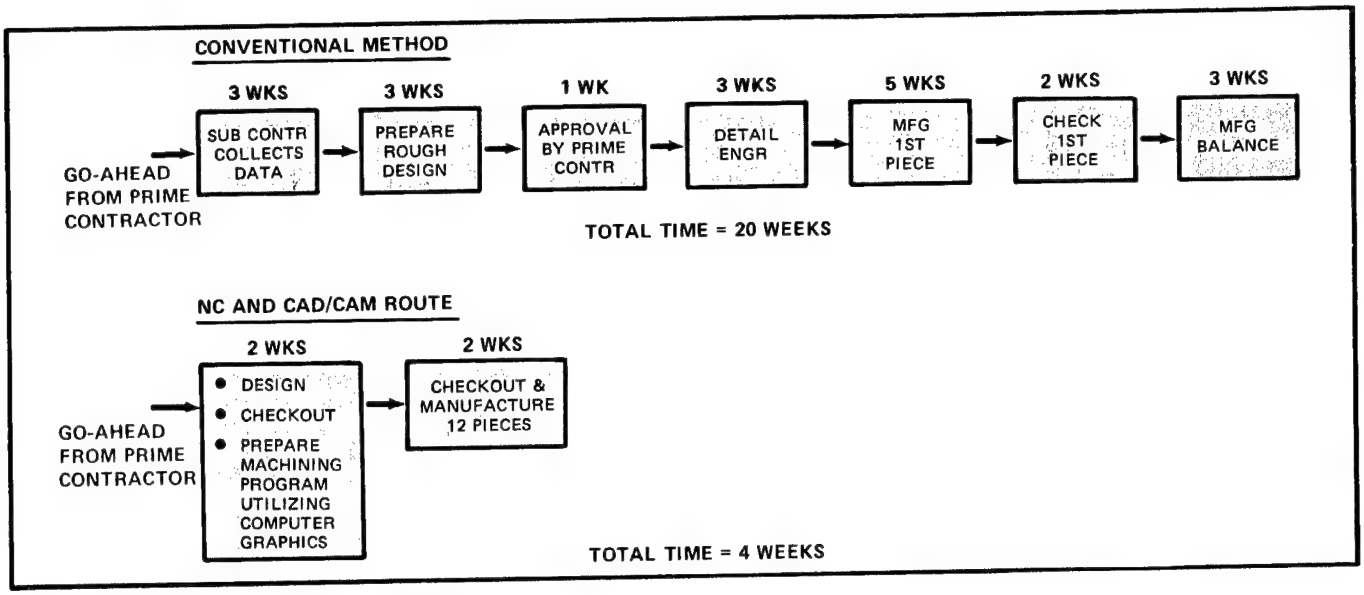


FIGURE 2

Keys to Reduced Lead Time

To get a further handle on the problem, six major shell manufacturers were visited in order to identify key factors affecting lead time. These manufacturers agreed that three factors are important. In some detail, these are:

• **Scarcity of Skilled and Experienced Personnel.** The large number of skilled workers needed for a buildup is practically impossible to come by in the short term. In the first place, it is extremely difficult to recall, or even to find, personnel that were laid off as a result of a previous cutback. Furthermore, the required craftsmen, especially toolmakers and machinists, are becoming scarce. For example, the Bureau of Labor Statistics predicts that by 1980 only 53 percent of the total industry requirement for machinists and toolmakers will be satisfied, assuming that operating conditions continue as they are.

One way to overcome this problem would be to improve wages in these trades and thus encourage more people to enter them. There is only a small difference in compensation between the skilled crafts, which usually require from 4 to 6 years of apprenticeship, and the unskilled or semiskilled trades, which by comparison require little training. However, raising wages for these skilled workers would also raise costs. Since the goal is to reduce costs as well as lead times, this is not an attractive alternative. A more logical approach is to implement advanced manufacturing techniques, such as numerical control and CAD/CAM, which will reduce the requirement for skilled labor.

• **Obsolescence of Inactive PEP Lines.** In general, inactive manufacturing lines are not kept abreast of either engineering or manufacturing changes. The field survey of six manufacturers indicated that certain shells have undergone numerous manufacturing and in-process changes over several years. Yet, very few of these changes have been incorporated into inactive manufacturing lines. (Nor are they part of the Army record, which would be the primary source of information in the event of mobilization.) In a number of cases, different revisions were assigned the same revision letter in the record. Obviously, this created a further source of confusion and delay. According to the field survey, this lack of firm, detailed, and up to date design and manufacturing information is one of the most serious causes of delay during a buildup period. This is true not only for the product, but also for manufacturing equipment, spare parts, and other facilities.

A practical solution is to establish a self checking design and manufacturing computer data base. This could be maintained by the contractor and monitored by the Army to insure its currency. With computer control, the updated equipment, facilities requirements, and NC programs for tool manufacture would be maintained in the computer data bank for ready retrieval in the event of mobilization.

Tooling Delays. The lead time presently required to design, manufacture, and check out tooling for a particular shell in its latest version is too long. For example, delivery of a lathe collet for holding the shell during machining may take 28 to 33 weeks. This collet has to be designed and manufactured to suit the machine tool and the shell. Figure 2 illustrates the operational flow for 12 collets manufactured by a small contracting shop. In this case, the cooperation and communication between the prime and the tool-

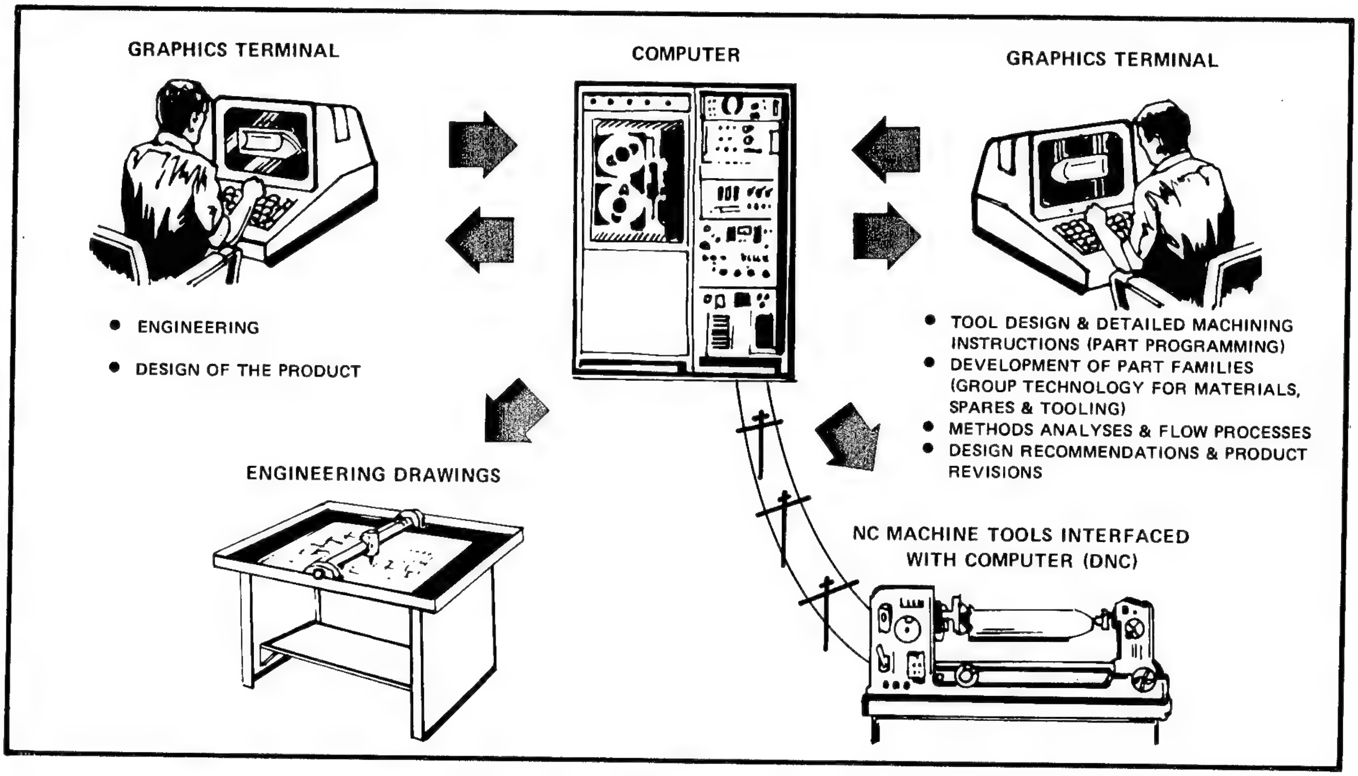


FIGURE 3 — COMPUTER SYSTEM
PRESENTLY IN OPERATION AT FRANKFORD ARSENAL

ing contractors were considered better than average. Yet delivery still required 20 weeks, far from satisfactory.

ARRADCOM estimates that no more than 2 weeks of engineering time would be needed for the same job using computer graphics to design and modify the tool and for simulated testing and fit. Furthermore, if detailed machining instructions are prepared using graphic terminals and numerical control, the time for engineering and also manufacture should be less than 4 weeks total.

Probably as significant as the reduced flow time and cost is the fact that the NC machine tools require less skilled personnel. The NC machining will also allow any required follow-on tooling to be produced in an even shorter period, since the program and tapes for operating the NC machines will already have been prepared.

ARRADCOM Program Described

As described briefly above, the three major factors affecting lead time and cost—skilled labor, obsolescent plants, and tooling delays—can be attacked by implementing a computer data base coupled with a graphics design capability. This is the type of system ARRADCOM is attempting to develop through TRACIM. Input through a graphics terminal will update a data base describing the latest product designs, manufacturing operations, material requirements, equipment and facility requirements, and NC programs for tool manufacture. The computer system will also handle design development for both product and tooling as well as the manufacturing flow process.

Figure 3 describes the computer system for the TRACIM project. All required computer hardware is presently operating within ARRADCOM. Much of the required software is presently in use with this system also. This includes the engineering graphic design programs and the numerical control programs for preparing the detailed machine tool instructions. Other programs have been ordered and will be implemented. These include family of parts programming, a classification and coding system for implementing group technology, and process planning programs.

ARRADCOM believes that this is the most comprehensive computerized design/manufacturing system within the U.S. Army. It includes the capability for engineering design and calculation via graphic input terminals, plus the capability for simultaneous preparation of NC machine tool tapes. Full-scale engineering drawings are

FIGURE 4

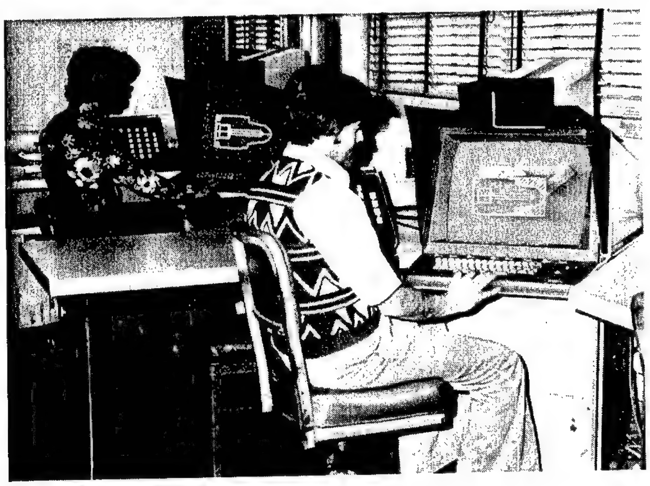


FIGURE 5

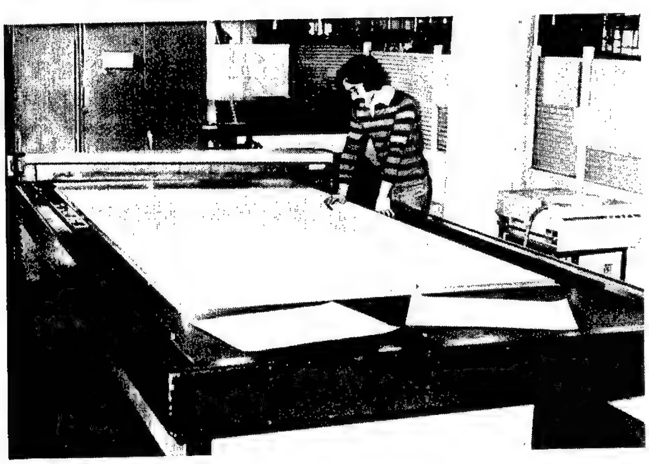


FIGURE 6

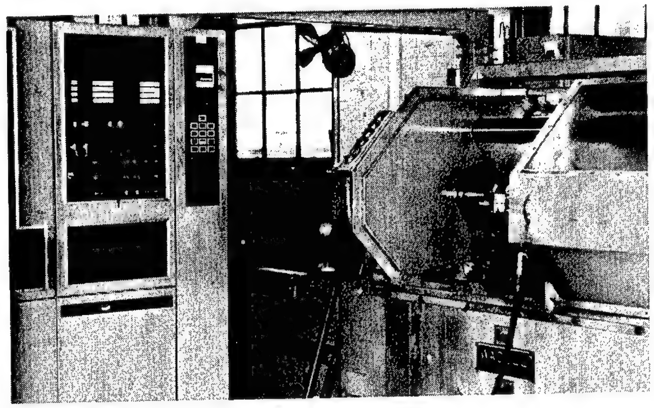


FIGURE 7

automatically prepared from the graphic input data via a large drafting plotter. The plotter can also digitize engineering prints and empirical curves utilizing closed circuit TV apparatus. Additionally, the computer can be hooked directly to NC machine tools in the shop by telephone lines. This arrangement eliminates the need for NC tape. However, the computer does have a high speed punch for producing NC tapes when that input mode is preferred.

Figures 4 through 8 depict components of this computer system. The main computer frame with four of its input sources—magnetic tape, punched cards, punched tape, and keyboard—is shown in Figure 4. An auxiliary disc storage unit with storage for 30 million words is seen at the left.

Probably the most efficient programming input device is the cathode ray tube (CRT). The ARRADCOM installation includes two, as shown in Figure 5. An operator (engineer, designer, or programmer) uses the keyboard and cursor to input any two or three dimensional figure. After designing the part, the operator may input machining instructions, such as the speed and feed rate of the cutter, and the computer will automatically calculate the required path of the cutting tool. The display on the scope at the rear of Figure 5 is that of a punch for hot forging a 155-mm shell. The scope in the foreground illustrates the computer calculated path of a lathe cutting tool for machining the 155-mm punch. A full-scale engineering print of the CRT display can be prepared automatically on the plotting table shown in Figure 6. With a single instruction, the computer will also automatically print a numerical control tape for cutting the part.

One of the NC machine tools assigned to the TRACIM project is shown in Figure 7. This precision lathe operates on punched tape or directly from instructions generated by the computer. ARRADCOM engineers anticipate using this equipment for the manufacture of close tolerance tooling required for testing the output programs. For additional information, contact Stanley S. Hart (201) 328-3721, or AUTOVON 880-3721.

Brief Status Reports

ELECTROSLAG REMELTING OF GUN STEEL. The mechanical properties of several heats of AISI 4335 + V from five different manufacturers were compared and evaluated to determine the potential benefits of using ESR material for the production of alloy steel. Forged billets were heat treated at 975 F and subjected to tensile, impact, and microhardness tests. Chemical and electron microprobe analyses showed a variation in chemical composition and a variation in the distribution of compositional elements throughout the sample group. Test results indicated large variations in ductility and impact strength. It was determined that mechanical properties are affected by distribution of compositional elements (as related to microhardness and hardenability) and by melting rates (as related to dendrite spacings). High hardenability permits a wider variation in melt rates without adversely affecting the mechanical properties. For additional information, contact V. J. Colangelo, (518) 266-5517, or AUTOVON 974-5517.

THERMAL MECHANICAL PROCESS FOR ALUMINUM ALLOYS. Ingot thermal mechanical processing treatments (ITMT) were developed for aluminum alloy 7475 plate and forgings. The new process was designed to give controlled delamination of armor material during ballistic impact. Aluminum plate processed by ITMT is being considered for use as an armor component in the XMI tank, and the aluminum forgings are being considered as components in the UTTAS helicopter. The aluminum alloy may also be used as an alternate material for the AMCAWS-30 cartridge case. For additional information, contact Mr. Donald Fischer, (201) 328-6714, or AUTOVON 880-6714.

ENDURANCE PUMPING TESTS WITH MOLTEN EXPLOSIVES. A Lapp hydraulic diaphragm pump with improved TFE disc diaphragms has successfully undergone 200 hours of pumping molten (200 F) Composition B. The pump was disassembled after 43, 102, and 200 hours for inspection. Slight stretching of one of the diaphragms was observed at the 102 hour disassembly. After completion of 200 hours, deformation of the diaphragm did not progress and pump performance was not impaired. The newly developed fiber optic leak detector (for checking diaphragm failure) performed satisfactorily in these tests. Contact Mr. P. Skerchock or Mr. B. Piper on AUTOVON 880-4252 for further information.

HUMIDITY SENSOR. A small humidity sensor shows great promise for determining humidity levels in confined areas such as within a mask, under hoods, and inside protective garments. The new sensor has rapid response and is the size of a transistor. Circuit design and evaluation are planned. For additional information, contact Mr. Donald Fischer, (201) 328-6714, or AUTOVON 880-6714.

SUBSTITUTION OF INGOT IRON FOR GILDING METAL/COPPER ROTATING BAND BLANK. This project was undertaken to find a substitute band material to replace a critical material (copper) without degradation of the performance of the projectile. A secondary benefit is reduced cost estimated at $2/ round for the 8 inch M106 and $.60 for the 105-mm M1. Manufacturing parameters will not be altered, as conventional band application and machining techniques will be used. The feasibility of soft iron as a rotating band material has been demonstrated by dynamic testing in the 8 inch howitzer system. Final ballistic testing is presently being conducted for the 105-mm howitzer. The results of the MMT project were recognized as a superior technical achievement at the 1976 Frankford Arsenal Technical Symposium. For additional information, contact Mr. William Pryor, (201) 328-4869, or AUTOVON 880-4869.

PROTECTIVE MASK XM29. A new mask developed by Sierra Engineering Company is undergoing evaluation tests. Investigators are continuing studies to develop coatings for silicone rubber used in the faceblank of the new mask. A dual coating system uses a fluorinated ethylene propylene rubber and polyurethane elastomer. The coatings are optically clear, are flexible across the range of operating temperatures, and provide a tough, scratch resistant coating for the facepiece. For additional information, contact Mr. Donald Fischer, (201) 328-6714, or AUTOVON 880-6714.

COAL GASIFICATION. Chemical engineering support is being provided to DOE in its research efforts to produce pipeline gas from coal. Plants will demonstrate different processes for producing gas (1,000 Btu) and liquids from coal and will feed from 2,500 to 7,500 tons of coal per day. Demonstration plant costs are estimated to run from $400–$800 million each. A full-scale production plant that can handle 50,000 tons of coal per day has a potential cost of two billion dollars. The plants are complex chemical production units of a type never considered before in the United States and are equivalent in complexity to major oil refineries. For additional information, contact Mr. Donald Fischer, (201) 328-6714, or AUTOVON 880-6714.

COMPUTER SIMULATION OF AUTOMATED LINES. A computer program, GENMOD, has been developed for automated production lines of munitions. The simulated technique provides a fast, low cost, and flexible method of design analysis. It is an effective alternative to actual preconstructions such as pilot lines and scale models because a year's worth of production can be simulated in a matter of minutes. The computer program generates a paper study in which machines are represented by sense flags, conveyors by counters, and assembled parts by binary digits. Input factors include failure/repair patterns of each operation in the production line plus cycle times, defect rates, and maintenance requirements. Information returned to engineers normally includes total material produced, raw material consumed, parts rejected, machine efficiency data, overall system availability, and cost estimates. For additional information, contact E. E. Loniewski, (201) 328-5817, or AUTOVON 880-5817.

BOMB ROVERS. The bomb rover can be used by bomb disposal squads of municipal police departments, the military, or other government agencies to safely transport hazardous materials and safely contain a 20 lb explosive charge. This trailer mounted explosive container weighs 1200 pounds, is inexpensive, and is towable by a passenger vehicle. For additional information, contact Mr. Donald Fischer, (201) 328-6714, or AUTOVON 880-6714.

WASTE DETOXIFICATION. Under an interagency agreement with EPA, a series of hazardous and toxic materials was identified that presented difficult disposal problems. Materials included polychlorinated hydrocarbon insecticides, chemical pesticides, and polychlorinated biphenyl. A research program was outlined to determine if the chemical compounds could be detoxified and transformed into a range of reusable by-products. The materials were subjected to a number of treatment processes including amine reactions, incineration, alkali treatment and hydrogenation, and sulfonation. For additional information, contact Mr. Donald Fischer, (201) 328-6714, or AUTOVON 880-6714.

EVALUATION OF PROTOTYPE EQUIPMENT FOR THE CONTINUOUS AUTOMATED PRODUCTION OF MULTIBASE SOLVENT PROPELLANT. A series of process parameter studies are being conducted at Radford AAP on the evaluation of prototype equipment for the continuous production of multibase solvent propellant under MMT Project 57X4202. These studies are being conducted on triple and double base propellants, M30, M30A1, and M26. Accurate, good quality cutting of grains was found to be highly dependent upon the temperatures of the strand prior to reaching the cutter. In order to reduce conveyor lengths and related construction costs, supplementary cooling of the strand on the conveyor between the extruder and cutter was obtained using a vortex cooler. Contact Mr. L. Lempicki, AUTOVON 880-3637, for further information.

ARBAT RADAR PROGRAM. A radar based instrumentation system has been developed for the fast detection and identification of defects leading to ammunition malfunctions. The ARBAT ("Application of Radar to Ballistic Acceptance Testing of Ammunition") System is an integrated ballistic data gathering and processing system consisting of a radar sensor and an onboard digital signal and data processing system. Ballistic test data is presented on a display console for immediate evaluation and at the same time stored on magnetic tape for later analysis. The prototype schedule calls for completion and proveout by January 1978. The first operational unit is planned for June 1978. For additional information, contact O. A. Briedis, (201) 328-6534, or AUTOVON 880-6534.

GROUP TECHNOLOGY. ARRADCOM, through Frankford Arsenal, has explored available group technology systems, one of which is being implemented. Recent advances in computer software for group technology have expanded its application to more efficient design, manufacturing, procurement, labor and equipment utilization, maintenance, service functions, etc. The computer will automatically prepare optimum flow patterns, estimated costs, and detailed operation sheets. It is expected that the system will be expandable with access to a common data base by all Army activities throughout the entire product life cycle. For additional information, contact Mr. Stan Hart, (201) 328-3049, or AUTOVON 880-3049.

QUALITY CONTROL OF NITROGUANIDINE MANUFACTURING PROCESS. An investigation of analytical methods suitable for the quality control of process streams in the nitroguanidine facility being constructed at Sunflower AAP was conducted under MMT Project 57X4169. A rapid and accurate colorimetric method for ionic guanidinium was developed which is suitable for the strong acid solution in the sulfuric acid concentrator subsystem. The procedure was found to be suitable to other process streams as well. Additional methods will be developed under subsequent MMT Project 5784447. For further details, contact Mr. C. Lewis, AUTOVON 880-3637.

MOLDED FIBER METHODS OF MAKING COMBUSTIBLE AMMUNITION COMPONENTS. This process uses an aqueous slurry system which includes cellulose nitrate fiber with other fibers and a resin emulsion, all slurried in large volumes of water. This mixture is drawn by vacuum onto a screen covered hollow contour form, depositing the fibers on the screen. This mat of fibers and resin, having the general contour of the item desired, then is molded and dried in one operation, and subsequently trimmed. Ammunition items currently made by this method are nonmetallic cartridge cases, igniter tubes, and mortar propellant increment containers. For additional information, contact I. G. Nadel, (201) 328-4776, or AUTOVON 880-4776.

DANIEL R. TURK serves as an Operations Research Analyst for the Decision Models Directorate of the Joint Conventional Ammunition Program Coordinating Group, Rock Island Arsenal, Illinois. He specializes in the application of modern analytical techniques to broad systems management problems. Prior to this assignment, he served four years as Staff Engineer to the Director of Research, Development, and Engineering, U.S. Army Armament Command, and twenty-two years as an engineer, consultant, and professor in industry and education. He is a graduate of Northrop University, where he earned Bachelor of Science degrees in Aeronautical and Electronics Engineering; he received his Master's degree in Operations Research and Industrial Engineering from Texas A&M University. A Certified Professional Logistician, Mr. Turk is a member of the Executive Committee of the Quad Cities Chapter of the Society of Logistics Engineers. He also is an active member of the Information Theory Group of the Institute of Electrical and Electronic Engineers, the Institute of Management Sciences, and the Operations Research Society of America.

New Decision Tool for Executive Planners

Model Weighs Conflicting Objectives

Sound management is no longer merely a matter of optimizing the cost picture. Noneconomic goals—social responsibilities, public and labor relations, etc.—may take even higher priority than economic goals. Most management decisions in today's complex world (in both government and industry) involve consideration of the importance of several objectives. More often than not, conflicting objectives. In any case, a single decision may involve setting priorities for several objectives. The answers are neither simple nor clear-cut.

For example, consider the difficult decisions facing DoD managers in the trade-offs required in the annual planning, programming, and budgeting cycle. Their problem is to develop balanced project/program portfolios for the Five Year Defense Program. The manager must be certain that he has the most cost effective and efficient plan to satisfy short and long-range goals and priorities.Further, the plan must fall within logistic and fiscal guidelines for the resources involved.

Goal Growth Programming the Key

Managers in industry and in other non-defense oriented branches of government face much the same problems and conflicts in their planning as do DoD managers. To meet the widespread need for assistance in long-range planning, The Decision Models Directorate of the Joint Conventional Ammunition Program Coordinating Group (JCAP) has developed a Priorities Model based on a new technique—Goal Growth Programming. The technique presents a method for resolving large complex decisions by structuring problems to incorporate growth for all mission goals. Quantifying of the issues and objectives, goal measures, and priorities leads to better understanding and to increased confidence in the final alternatives presented for decision. It was first developed to model multiple trade-offs that best reflect management objectives and priorities while considering the total decision environment, goal priorities, and growth achievement of goals. The JCAP Priorities Model, registered as a DoD logistics model, utilizes Goal Growth Programming to evaluate and rank alternative decisions for maximum achievement of overall management goals, both economic and noneconomic.

Uses for the computerized model go beyond the annual planning, programming, and budget cycle; they include applications to Goal Growth Management Programs, Command Review and Analysis Programs, Project and Program Management as well as the upgrading of formal Management by Objectives programs.

Model Offers Many Pluses

The model has potential for widespread innovative application; it can be used to

- Provide optional planning portfolios which are logically consistent with management goals and objectives
- Incorporate current priorities into medium or long-range planning
- Enable integrated intermanagement planning and visibility for high level goals
- Offer alternative plans which are optimal for budget constraints or strategies
- Determine best remaining options after incorporating management overrides
- Indicate critical problem areas
- Provide a method for processing vast amounts of complex information.

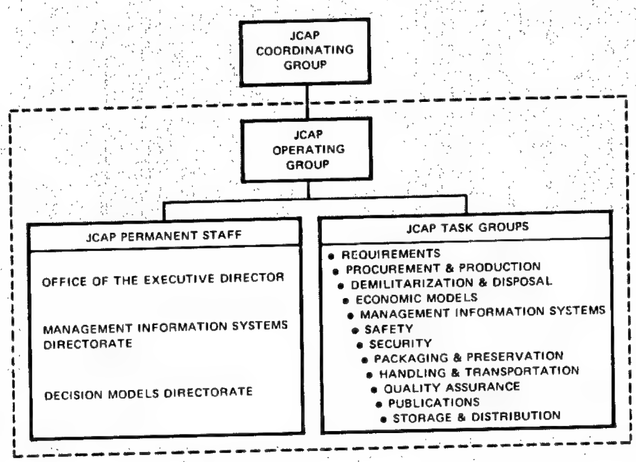
Many Issues Involved

Development of the Priorities Model requires a systematic approach to rationally balance the multiple objectives that influence a final plan. To accomplish this, the model must address many questions; the major issues involved are:

Defining the Problem. What is the basic decision problem? What alternatives are available to the decision makers? How stringent are the planning limitations imposed by logistic and fiscal guidance? Are the overall management goals already formally defined or must they be synthesized? How should broad program priorities and existing commitments be handled? Must individual project selection be sequential? The identification of these and all other significant impacts of potential decisions must be examined and

Payback Ratio Over 200 to 1

JOINT SERVICE GROUP MANAGES MUNITIONS



Military management decisions helped by modeling techniques have identified potential cost savings of over $1 billion during operations by the Joint Conventional Ammunition Program Coordinating Group. These potential savings translate into a payback ratio of over 200 to 1 for the resources invested in the JCAP program.

The Joint Conventional Ammunition Program Coordinating Group representing the Army, Navy, and Air Force exercises coordinated joint service management of the DoD ammunition program. Chartered by the Joint Logistics Commanders in 1972 to achieve efficient, effective, and economic management of the armed forces' conventional ammunition production and logistics activities, the Coordinating Group consists of the top materiel readiness and logistics commanders from all the military services, with a civilian director for liaison.

The Coordinating Group's directives are implemented by an Operating Group staffed by both military personnel and civilians monitoring the activities of the Task Groups and staff organizations shown on the accompanying chart. The JCAP Decision Models are **dynamic economic models** specifically developed by the Decision Models Directorate by directive from the Coordinating Group. They answer the imperative questions of how, when, where, and to what extent should resources be committed to best achieve the primary mission of this management team—**maximum overall readiness**. Each model identifies a set of best available alternatives for the decision maker's evaluation and selection. These models are ready for implementation by command and functional managers

The JCAP Decision Models include

- The Item Acquisition/Production Trade-Off Model
- The Materiel Acquisition Planning Model
- The Industrial Preparedness Model
- The Maintenance Model
- The Production Facilities Life Cycle Cost Subsystem
- **THE PRIORITIES MODEL**
- The Multiple Bid Evaluation Model
- The Demilitarization and Disposal Model
- The Ammunition Packaging/Containerization Life Cycle Cost Model

For those desiring additional information, contact Mr. B. C. Witherspoon (309) 794-5262 or AUTOVON 793-5262.

Editor's Note: Articles describing more of these joint service management models will appear in future issues of the Army ManTech Journal.

discussed during the problem definition phase so that the model will reflect the decision environment and accommodate the proper constraints.

Establishing Goals and Priorities. The multiple and often conflicting goals of an organization vary according to its missions and functions, according to its interrelationships with other organizations and management levels, and according to its management philosophy. In achieving a set of goals, the decision maker is often hampered by conflicting interests, incomplete and irrelevant information, limited resources (or scarcity of resources), and pressing schedules. Evaluating goals and priorities clears the decision environment. Such evaluation can be accomplished by structuring the problem through a tree-like hierarchy that progresses from goal to subgoal to objective to performance measures. Branches of the goal tree must end on specific performance measures or estimates of judgmental value. Some goals are measurable, others are subjective. Each branch must be quantified and weighted according to goal priorities. The modeler must identify trade-offs of goal achievement via assessment techniques varying from direct proportionment to statistical assessment of group preferences. The decision maker must be comfortable with weighting factors and variations imposed in the model trade-offs. He is in direct control—the source of all value judgments.

Acquiring and Interpreting Data. Once performance measures have been identified, they must be expressed as numerical data having special informational value in the trade-offs. All aspects of data processing must be addressed. Is the definition for each factor clear? What data is now collected? Is it appropriate for these goals? If not, can it be reprocessed to suitable form? What new data is needed? Which activities should submit which data?—when?—how? Examination of the existing data packages and interrogation of experienced members of review teams constitute good starting points for realignment of data processing aspects. The problem is to bring order and credibility to a process that often appears to be in chaos.

Choosing Criteria. Two objectives common to all decision makers are "high return" and "dependability". To accommodate different interpretations for high return in multiple objective situations, goal priorities must be determined. Goal growth attainment is a universal objective. Dependability is significant because of future technological uncertainties. Project selection thus may require Decision Risk Analysis (DRA), with its increased data collection, statistical complexity, and interpretation of the decision options.

The Priorities Model At Work

The Priorities Model presented here has widespread potential. It is comprised of a group of procedures and programs that evaluate and rank decision alternatives for maximum planned growth to multiple goals in accordance with goals and priorities established by the manager.

The model applies to complex planning problems where determination of management objectives must consider goals for productivity, economics, and social impact, as well as broad priority levels, specific goal priorities, and practical resource constraints. Obviously, complete achievement of all goals in most situations will be impossible. This is why trade-offs are necessary and why a modeling technique is needed to assist the manager in making the best trade-offs to maximize overall achievement.

Normally, the model's default mode does this by selecting portfolios that minimize the sum of underachievements of goals over the planning period. Overachievements are a bonus. The decision maker may select other rules that provide the best combination of near term growth or best "track" goal targets. After the initial run, the decision maker can thus "drive the model" and guide its selection process. Computerized graphics allow him to see the results of strategy variations.

Complex Planning Made Easy

The Priorities Model can resolve growth plans of 1 to 20 years for up to nine goals in as many as 100 project/planning periods (for example, 100 projects over 10 years or 200 projects over 5 years). Analytical processing programs aid in subjective assessment. The decision maker uses a preprocessor module to further shape goal paths and to obtain a

realistic solution based on the best weighted average growth plan attainable under the goal priorities he has defined. Figure 1 indicates typical target goal growth plans generated automatically in response to priority assessment and current goal status.

After the target paths are approved or revised and other factors influencing the scope of the investigation are decided upon, (for example, budget variations and criteria choice), another program sets up a file of project data and automatically generates a matrix file of governing relationships. The two files are then run with a commercially available program with special capabilities for this type problem. Equations used in Goal Growth Programming are converted by the matrix generator into a program file for mixed integer solutions. Here, variations between target Goal Growth plans and what could be achieved by combinations of projects (within defined restraints) become under or overachievement variables. The criteria selected, such as minimizing the sum of underachievements, drive the software package to its solution for the portfolio best meeting the objective. Other portfolios are listed in the output in ranked order by use of a predetermined selection rule (for example, list the five best plans).

Figure 2 summarizes input requirements, the main processing steps, and output of the Priorities Model. The report generator module adds decision aiding evaluation measures such as growth/cost index and values of other possible criteria. It provides an analysis of the problem solutions for the decision maker.

Management Function Simplified

Goal Growth Programming encourages evaluation over multiple time periods and extension from dynamic to static situations, while simplifying the manager's part in the process. The manager maximizes his control, his credibility in the modeling process, and his effectiveness in the decision process. The basic steps in the modeling process are as follows:

Step 1. Identify the Players and Their Roles. Figure 3 indicates the players and their roles. The executive decision maker is the source of all goals and objectives and of their

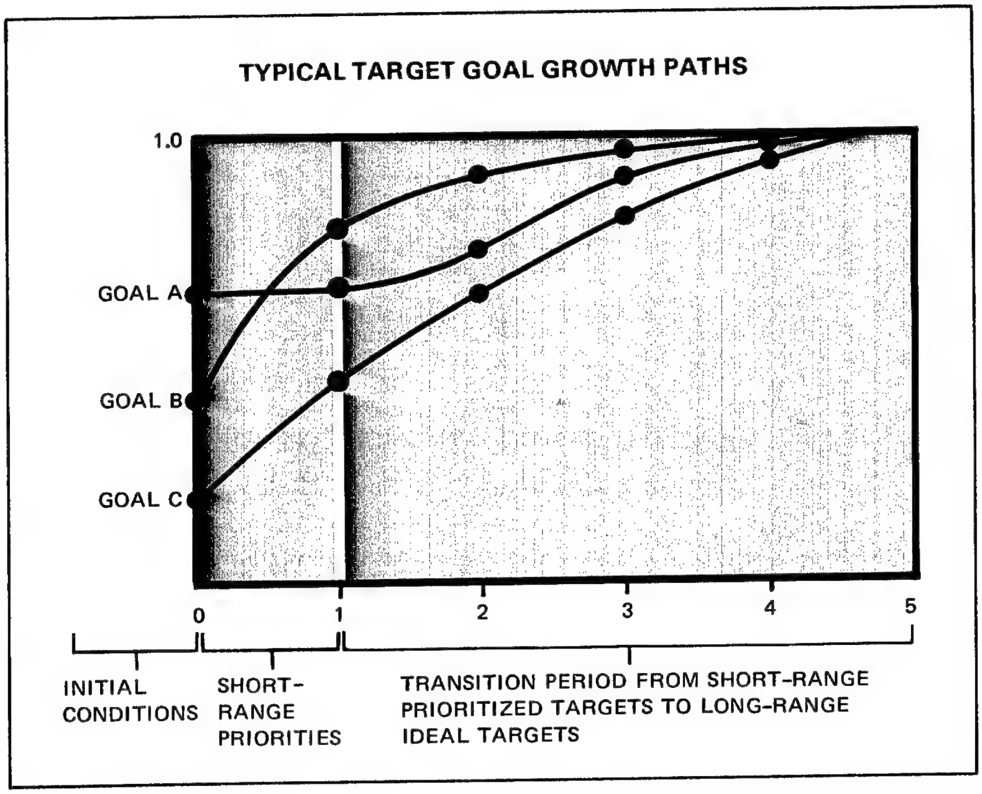


FIGURE 1

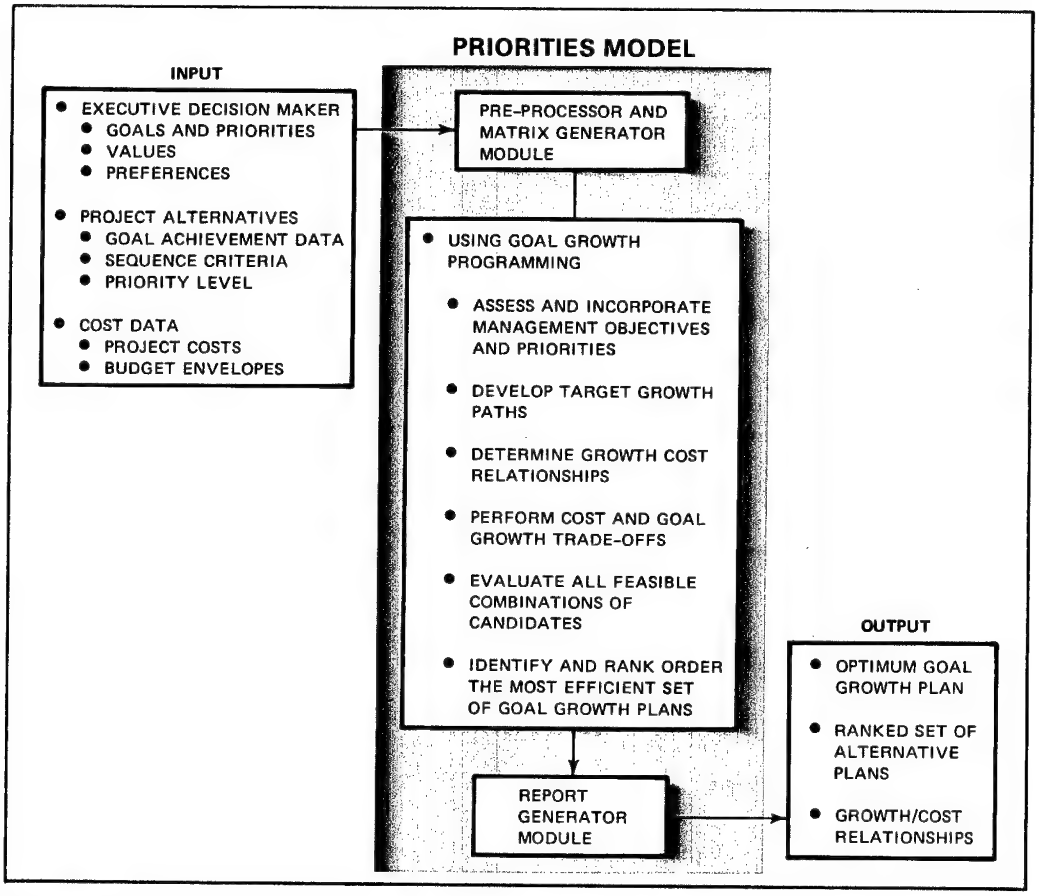


FIGURE 2

PARTICIPATIVE DECISION MAKING

CAST:	ROLES:
EXECUTIVE DECISION MAKER	• ESTABLISH GOALS AND PRIORITIES • DELEGATE INFORMATION RESPONSIBILITY • APPROVE TARGET GROWTH PATHS
MANAGERS AND STAFF	• ADVISE, COORDINATE AND EVALUATE • PROVIDE SPECIALIZED EXPERTISE • MONITOR INPUT/OUTPUT
DECISION MODELER	• CONVERT INPUT TO MODEL FORMAT • GENERATE TARGET GROWTH PATHS • OPERATE THE MODEL • PROVIDE MODEL OUTCOMES (PORTFOLIOS)

FIGURE 3

associated values. The managers and staff support both the decision maker and the modeler by applying expertise and data. The decision modeler converts all source information into model data that reflects the decision maker's goals and priorities. The model will then select and combine the decision alternatives into efficient planning portfolios for the decision maker's final selection.

Step 2. Identify the Goal Set. Goal achievement is the basis for evaluation, and the true objective in multiple objective problems. Often, the management goals are not nicely structured. For example, the goals of the DoD Conventional Ammunition Program structured in Figure 4 were synthesized from many sources. Goals 1 and 2 concern the primary mission, Goals 3 and 7 are economic, and subgoals of Goal 6 are major non-economic factors. These goals address the entire program under one manager. They are subdivided into specific goals and objective pairs, as shown in Figure 5. Even these pairs

GOALS: DOD CONVENTIONAL AMMO PGM

1. IMPROVE READINESS (PRODUCTION BASE)
2. IMPROVE READINESS (LOGISTICS BASE)
3. REDUCE COST (BOTH BASES)
4. IMPROVE P&P PROCESSES
5. IMPROVE QUALITY OF WORK FORCE
6. IMPROVE IN SPECIAL CONCERN AREAS (SAFETY, ECOLOGY, SECURITY, STANDARDIZATION, QUALITY, FLEXIBILITY)
7. MANAGE AND OPERATE AT MINIMUM APPLICATION OF RESOURCES (FACILITIES, PERSONNEL, DOLLARS)
8. IMPROVE EEO RATIOS
9. IMPROVE WORKING/LIVING ENVIRONMENT (FACILITIES, EQUIPMENT, COMMUNICATION, SERVICES)
10. FOSTER AND UPGRADE (CREATIVITY AND INITIATIVE, PROBLEM IDENTIFICATION AND ELIMINATION)

FIGURE 4

GOAL NO. 4 IMPROVE THE CONVENTIONAL AMMUNITION PRODUCTION AND PROCUREMENT PROCESSES

GUIDANCE. THE ATTAINMENT OF THIS GOAL REQUIRES BOTH APPLICATION OF IMPROVEMENTS TO THE PRODUCTION TECHNOLOGY BASE AND IMPROVED SURVEILLANCE OF PRODUCTION TO RECOGNIZE POTENTIAL SCHEDULE SLIPPAGES AND OTHER CONTRACT DELINQUENCIES AS EARLY AS POSSIBLE IN ORDER THAT TIMELY CORRECTIVE ACTION CAN BE INITIATED.

GOAL-OBJECTIVE

PAIR 4-1: IMPROVE PRODUCTION PROCESSES THRU MM&T

PAIR 4-2: DEVELOP AND OBTAIN MORE REALISTIC CONTRACTS

PAIR 4-3: IMPROVE VISIBILITY FOR HIGH PRIORITY/LARGE VOLUME PROGRAMS

FIGURE 5

are too broad to be useful in analyzing and calculating specific decision alternatives. They must be divided further into lower level, more specific objectives, thus starting a goal objective hierarchy. Each manager applies a goal achievement importance rating to each goal according to his insight and interpretation. These ratings are totaled.

Step 3. Form the Goal Objective Hierarchy. As shown in Figure 6, a goal hierarchy ladder is formed at increasingly detailed sublevels. Theoretically, a single score for all ten goals can be determined by rolling back to the left. This approach is beneficial when a few alternatives must be examined in great detail—for example, site selections. For the

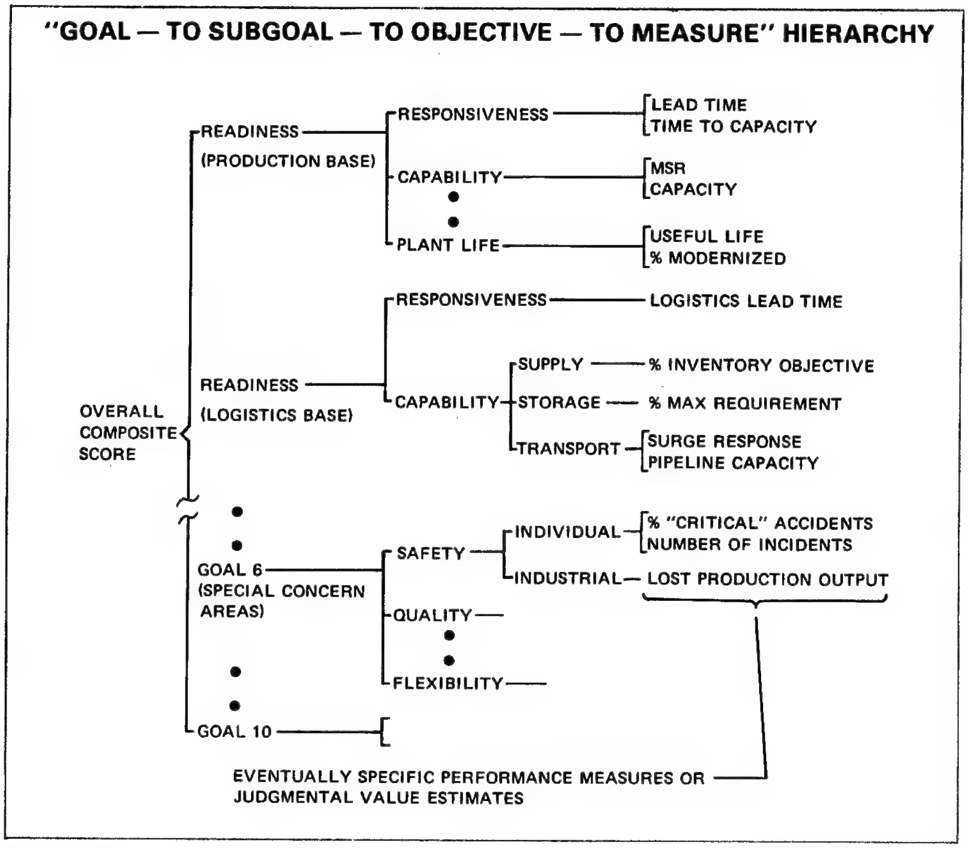


FIGURE 6

project portfolio type of problems faced by the Priorities Model, a simpler structure is developed. Six basic questions addressed to a base modernization project might be:

(1) How much will the project improve base performance?
(2) Will it improve base hazard status (how safe is it)?
(3) How well will it meet other goals (any fringe benefits)?
(4) Can we afford it?
(5) Is it mandatory?
(6) What are the chances for success?

Such questions clarify the main issues and better define the problem. The first three address goal achievement and thus aid in structuring the goal tree; the final three—addressing budget, risk, and priorities—clarify the constraints to a goal growth problem. A simplified goal structure emerges, as shown in Figure 7.

Step 4. Develop Goal Measures, Values, and Data Collection Procedures. After goals are agreed upon they must be quantified. For a goal growth approach, the upper limit is an ideal attainable value and the lower limit is zero attainment. Some data measurements are straightforward (months, units/man); other data must have subjective values applied. Various techniques, statistical and otherwise, are applied to this data so the values are credible and faithfully reflect the decision maker's preferences. Practical, easy to understand procedures for consistent estimating and transformation to standard format in the data processing operations are a must. In the model, each alternative is evaluated as to improvement for each goal—thus, "before and after" analysis in data collection is important. Finally, the improvement rating must be transformed via an effect factor, such as a continuous curve or a finite set of utility values over the set of ranges in improvement.

Step 5. Determine Rules of the Game. Here, other factors and rules are added so that priorities are met in order of importance within budget or time constraints. Also, any sequencing or concurrency rules are considered.

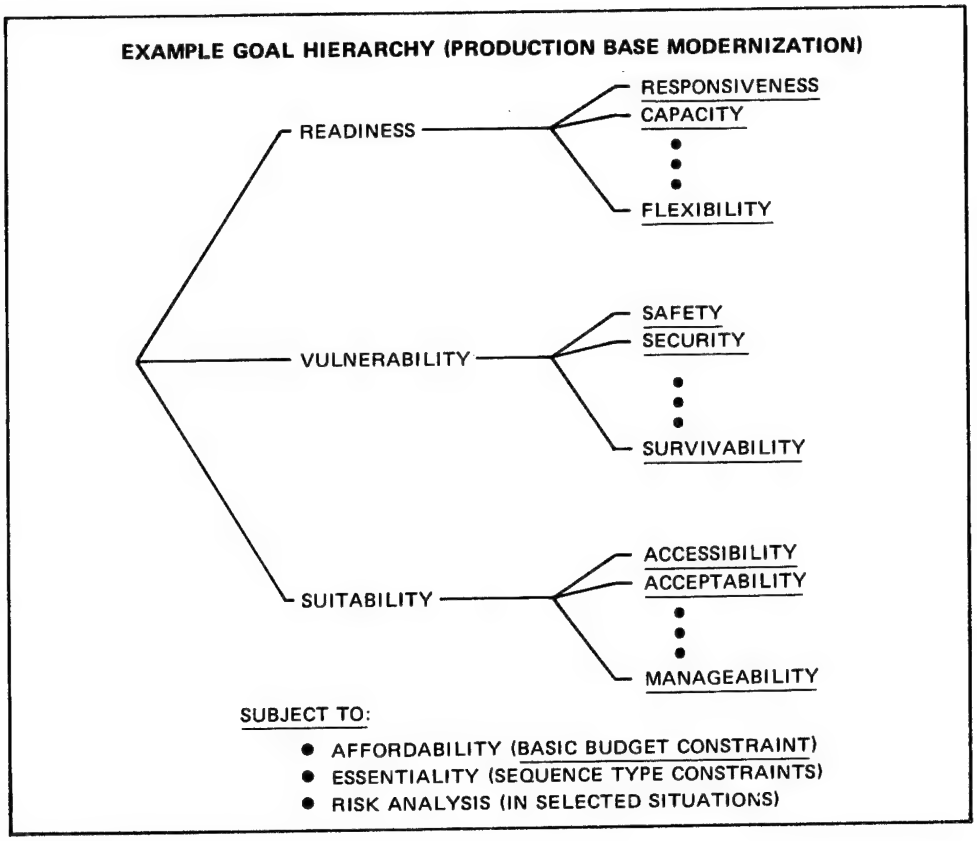


FIGURE 7

Step 6. Assess Current Priorities and Needs. This critical step determines the relative importance the decision maker places on achievement of each goal in the near future. Trade-off preferences between goals at various goal achievement levels are determined by subjective assessment techniques. These preferences, combined with individual goal utility values from Step 4, establish the basis for equations relating goal priorities. The result is a single management preference function, weighted to sum to unity, as shown in Figure 8 for a five goal base modernization problem.

A second facet of this step is to determine other evaluation requirements desired. Through a series of "what if" questions, the decision maker's areas of concern are met—for example, the effect of rising or falling budgets or of other's views, as in Figure 9. Completing this step provides all initial input data (see Figure 2) for the Priorities Model.

CURRENT GOAL PRIORITIES FROM TRADE-OFF ASSESSMENT

GOAL	GOAL MEASURE	GOAL PRIORITY
g_1	Reaction Time Reduction	.30
g_2	Cost Benefit	.22
g_3	Facility Condition	.23
g_4	Working Conditions (OSHA)	.14
g_5	Pollution Abatement	.11

FIGURE 8

GOAL		DoD INSTALLATIONS & LOGISTICS	SINGLE MANAGER FOR AMMUNITION	ARRCOM DIRECTOR PRODUCTION	GOGO/GOCO AMMUNITION PLANT MANAGER
1 – READINESS-PRODUCTION BASE		.05	.38	.15	--
2 – READINESS-LOGISTICS BASE		.30	.09	.07	--
3 – OPERATING/MAINTENANCE COST REDUCTION		.15	.03	.08	.25
4 – PROCESS IMPROVEMENT (PRODUCTION & PROCUREMENT)		.05	.16	.35	.05
5 – UPGRADE MANPOWER		.05	.04	.08	.15
6 – SPECIAL TOPICS		.10	.12	.05	.20
7 – MINIMIZE RESOURCES		.20	.16	.10	.10
8 – EEO PROGRAM		.05	.01	.02	.10
9 – UPGRADE	EQUIPMENT FACILITIES COMMUNICATIONS	.03	.01	--	.10
10 – MOTIVATE & CHALLENGE		.02	--	.10	.05

EXAMPLE GOAL WEIGHTS — VARIOUS MANAGERS

(WEIGHTING ASSIGNMENTS: SUM=1.0)

FIGURE 9

Step 7. Evaluate Goal Growth Paths. The preprocessor module, as previously mentioned, generates target goal growth plans in graphical format for the decision maker's review and adjustment. Current goal priorities from Step 5 and existing levels of goal attainment are used to help shape the target growth paths.

Step 8. Evaluate Preliminary Solutions. A second stage in the preprocessor supplies preliminary solutions. The solutions allow the decision maker to see goal attainment under various strategies, providing an overview of the decision environment. The preliminary evaluation is complete when final decisions have been reached on all factors affecting the computational processing module of the Priorities Model. These factors—goal priorities, initial conditions, budget variations, and broad program priorities—go into the matrix generator model for processing.

Step 9. Determine the Best Decision Alternatives by Goal Growth Runs. In this step, the main computational module of the Priorities Model follows the sequence shown in Figure 2 to improve upon the solution in Step 8 for each specified strategy, until an optimum goal growth plan and a specified number of alternative plans are attained. Each plan is a portfolio indicating a specific manner for combining and scheduling projects to achieve goal growth. The composite set of all plans represents the best alternatives available to the decision maker.

Step 10. Evaluate Alternatives and Submit for Decision. In the final step, a report generator module extracts cost and growth performance data for each portfolio and restructures it into graphs and charts for management oriented output. The modeler analyzes the report output and summarizes all alternatives for use by the decision maker and his staff in reaching the final decision.

Details offered

The Goal Growth Management procedure discussed here presents a means for resolving large, complex decisions; the method structures problems to incorporate growth for all mission goals. Quantification of the issues and objectives, goal measures, and priorities leads to better understanding and to increased confidence in the final alternatives presented to the decision maker.

Theory, example procedures, and calculations for applying the method are given in a complete report available from the author, (309) 794-5292 or AUTOVON 793-5292.

Increased Funding Ensures Continued Improvements

Helicopter Manufacturing

Part 3: Future Manufacturing Technologies

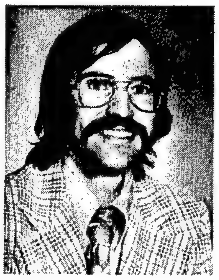
Projected helicopter manufacturing improvements by the Aviation Research and Development Command over the coming years will involve a closely structured procedure that will take into consideration not only cost savings, but aircraft performance and component producibility in order to arrive at a practical compromise between these major factors. Never will major aviation systems be implemented by the Army without the most careful evaluation of all these important aspects involving heavy investments of the nation's resources. We have discussed in prior articles the airframes, rotor systems, drive systems, and turbine engines and considered Manufacturing Technology (MT) programs that will provide significant cost reductions, improved reliability, longer service life, and more efficient production.

The MT program at the Army Aviation Research and Development Command (AVRADCOM) does not stop there, however. The already successful AVRADCOM program has received increased emphasis and will be funded at a higher level over the next 5 years. Consequently, an even greater effort toward improving helicopter manufacture and overall productivity can be expected.

Future Actions Carefully Planned

To launch this effort, Battelle's Columbus Laboratories has assisted AVRADCOM in formulating a course of action for aviation MT efforts. These efforts are designed to effect manufacturing improvements and to ensure component producibility during the next 5 years. In addition, during November 1977, AVRADCOM hosted a conference in Palo Alto, California, on Army Aviation Manufacturing Technology. Numerous potential MT projects were reviewed by working panels made up of representatives from the aviation industry. The results of this conference, along with the earlier information generated by the Battelle study, will be used to develop a comprehensive 5 year plan for the AVRADCOM Manufacturing Technology Program.

As part of its study, Battelle identified major manufacturing related helicopter life cycle cost drivers. This information was gathered through in-depth interviews with representatives of major airframe and engine contractors and subcontractors, as well as Army helicopter maintenance personnel. The cost drivers identified as important are listed in Table 1, together with potential actions to attack them. As seen, the methods used can be many and varied.



ROGER L. SPANGENBERG is an honor graduate in Aerospace Engineering of the University of Maryland and holds a Master's Degree in Industrial Engineering from Texas A&M University. He is also a graduate of the U.S. Army Engineering Intern Training Center in Product/Production Design Engineering. Mr. Spangenberg has spent five years with the Department of the Army in both technical and management capacities. At the U.S. Army Aviation Systems Command, he was project engineer for the development of advanced manufacturing technology for production of engine and airframe components used in Army helicopters. While at AVSCOM he also served as the Command's Computer Aided Manufacturing coordinator. In his present position at the U.S. Army Tank Automotive Command, Mr. Spangenberg is responsible for management of planning and programming for the XM-1 Tank Development. He is a member of the Tau Beta Pi, Sigma Gamma Tau, and Alpha Pi Mu honor fraternities, and he is a member of the AIAA and SAMPE technical societies.

Editor's note: This series of articles was written by Mr. Spangenberg while he was with the Production Technology Branch at AVRADCOM. Since completing the articles, he has assumed a new position with the U.S. Army Tank Automotive Research and Development Command. Readers wishing to acquire more information about AVSCOM's helicopter manufacturing technology program may contact Mr. Gerald Gorline or Mr. Dan Haugon at (314) 268-6476 or AUTOVON 698-6476.

echnology

Performance, Producibility Trade-off

Cost reduction is just one goal of the AVRADCOM program. Another is to acquire helicopters with optimum performance at an affordable cost. Concepts to improve upon performance and cost through use of advanced materials or designs are being investigated throughout Government and industry. Some of these advanced concepts may require a close look at producibility if they are to be implemented on the next generation of production helicopters.

Based upon their analysis of needed cost and performance improvements, Battelle identified areas where significant benefits can be realized by applying advanced manufacturing technologies. As a result, they recommended 12 major technical thrusts that AVRADCOM should investigate. These are the development of manufacturing technologies for:

- Composites
- Joining
- Reducing Repair and Maintenance
- Computer Applications in Manufacture
- Quality Control and NDT
- Reduction of Part Count
- Net Shape Processing
- Hot Isostatic Processing
- Production Ready Tooling
- Materials Related Developments
- Forging
- Casting.

Based on project suggestions received from both Government and industry, Battelle identified a number of specific actions that AVRADCOM could take within these broad technical areas. However, the ability of these actions to affect cost and performance varies between helicopter subsystems. Thus, the specific thrusts recommended by Battelle which AVRADCOM expects to pursue are more logically discussed for each of the four subsystems reviewed in Parts 1 and 2.

Composites Important to Airframe Technology

Battelle identified the development of manufacturing techniques in several specific areas as the most important thrusts in airframe technology over the next 5 years. These areas are:

- Composites
- Joining

Table 1

COST DRIVERS	POTENTIAL ACTIONS
High Labor in Assembly	• Adopt automation where appropriate • Reduce part counts • Modularize subassemblies for automation • Use coaxial wire harnesses • Develop production-ready tooling • Design for composites rather than substitute for metals
Excess Chip Removal	• Develop production tooling at early stage (see tooling) • Order in larger quantities (provide financial incentive) • Support efforts to produce near net shapes
Redundant Inspection	• Computerize inspection plans/results • Accept certification of vendors • Design components for ease of inspection
Tooling Costs	• Develop low-cost tooling for short production runs • Develop higher cost, long-life tooling for long runs
Repair & Maintenance	• Design for maintainability/accessibility • Use modular designs (easily replaced subassemblies) • Choose materials that last longer (sometimes higher cost)
High Part Count	• Convert/design for use of composite structures • Standardize as many fasteners as possible • Design for larger components to preclude joining small parts • Apply adhesive bonding more extensively
Design Costs	• Develop interactive graphics for drafting • Develop computer-aided design • Develop interactive graphics for assembly check out • Build computer data bank for material/cost/design trade-offs
Labor-Intensive Composites	• Develop automatic tape/fiber layup machines • Design for composites rather than substitute for metals • Standardize on fewer types of materials to increase volume • Use dry fiber rather than prepreg tape (resin at layup) • Develop guidebooks on design and use of composites • Develop effective/practical inspection procedures/standards
Small Production Buys	• Authorize larger inventory of parts/subassemblies • Eliminate separate left- and right-hand parts • Design for thermoplastics for high shelf life and large purchase

- Reduction of Part Count
- Production Ready Tooling
- Reducing Repair and Maintenance
- Quality Control and NDT.

The use of composite structures in helicopter airframes is currently limited to those secondary structures where relatively inexpensive fiberglass can be laid up into a variety of curved panels, hatches, and fairings. The application of composites to airframe primary structures is not yet widespread. There are three major reasons for this. First, the three primary filaments used in Army aircraft structural applications are Kevlar, graphite, and boron of various types and properties, which may be bonded together with any of a number of epoxy resins. Although providing greater stiffness than the glass used in secondary structures, they are also from 3–10 times more expensive. Second, the many possible combinations of fibers and matrices have kept the purchase quantities of individual combinations low and, as a result, their costs high. Finally, most composite structures must currently be laid up by hand, again resulting in expensive components.

Increased Utilization Logical

Add to these reasons the relative inexperience of designers and manufacturing engineers with these new materials, and we can understand the limited application of composite materials to date. However, it is evident that their use for a variety of structural and nonstructural applications will increase substantially over the next several years. A number of factors will contribute to this increased use:

- Significant part count reduction, reducing assembly time and eliminating joining by rivets
- Automatic or semiautomatic equipment providing the potential for significant labor reduction
- Wide variety of available materials providing an opportunity to select those with the specific characteristics needed for a particular application
- Reduction of facilities costs
- Reduction of machining operations, which are inherent in metallic construction
- Elimination of corrosion problems, reducing repair and maintenance
- Ability to easily produce complex, one-piece parts that would have to be produced by joining multiple pieces if made from metal
- Low energy requirements for fabrication when compared to metal processes
- Conservation of materials due to less scrap in built-up components (10 percent) as opposed to 35 percent for machined-down metal components
- Amenability to joining by adhesive bonding and to a combination of separate operations
- Significant potential weight reduction (35–75 percent)
- Fatigue lives three to ten times greater than those of conventional materials reduce repair and maintenance
- Wide variety of available forms such as fibers, tapes, sheets, foams, etc.
- Ability to combine attributes of more than one material in a structure by selective reinforcement
- Capability to offer ballistic and foreign object damage tolerance, reducing repair and maintenance.

Based upon the foregoing discussion, it is evident that the development of manufacturing technology for composite structures has a cascading influence on the development of manufacturing methods in the other key technological areas. Almost any effort in composites should result in reducing part count and reducing repair and maintenance. Joining operations will be reduced or redirected because of the ability to form complex structures from composite materials and through broader application of adhesive bonding. Production tools will be a large part of the composite technology effort where developments will be needed to derive the stated benefits of automated fabrication. The application of advanced quality control and NDT procedures will also be necessary, especially to determine the effects of presumed defects in composite structures.

A summary of some specific typical shortcomings in the manufacture of helicopter airframes and the specific thrust actions anticipated to solve those problems over the next 5 years appears in Table 2.

Table 2

Important Technical Thrusts: Airframe System

TYPICAL PROBLEM AREAS

- High labor content of composite structures
- Unreliable NDT of composite structures
- High cost of curing composite structures
- Cutouts and holes in composite structures cause localized weaknesses
- High cost of specialized composite materials
- Insufficient data on fiber-reinforced thermoplastics to permit implementation
- Joining of composite structures to metallic structures
- Panels with aluminum honeycomb require extremely close fit-up and costly anticorrosion measures
- High assembly costs for small production runs
- Excessive labor involved in the manual riveting of structures
- Large number of components
  - Rivets/other fasteners
  - Stringers
  - Left- and right-hand parts
- Large number of part designs
- Tooling for small quantities, while initially less costly, results in high labor costs when used for production
- Airframe forgings require extensive machining to chips
- Airframe structures are difficult and costly to repair/replace
- Influences of different types of discontinuities in composite structures not well understood

THRUST ACTIONS

- Molding of integral fiber-reinforced structures
- Integrally heated dies for curing structures during layup
- High-speed microwave techniques for curing
- Application of molded, reinforced thermoplastics
- Production of airframe structurals by braiding/pultrusion
- Production of low-cost lightweight cores
- Automated broadgoods layup for relatively simple shapes
- Emphasis on quality control/NDE of composite structures
- Improved structural designs tailored to composites
- Standardization of materials for composites
- Continuing attention to economics in use of composites
- Improved joining methods for joining composite to metallic structures
- Design guides describing when and when not to use composites
- A thorough assessment of applications and methods for joining composites with adhesives and/or mechanical fastening
- New close-outs for simplified assembly
- Broader application of rivet bonding
- Broader application of adhesive bonding
- Develop tooling for automated riveting of production panels/assemblies
- Adhesive joining of composite structures
- Standardization of components
- Redesign left- and right-hand parts for interchangeability
- Conduct cost trade-off studies between conventional and composite structures
- Determine where production ready tooling is a good investment over total production orders
- Identify where components and subassembly repair and maintenance can be improved
- Conduct studies related to the effects of "defects" in composite structures

Rotor Systems Also Stress Composite Technology

Battelle recommendations on MT programs for the major rotor systems over the next several years emphasize development of:

- Composites
- Production tooling
- Joining
- Quality control and NDT
- Computer applications in manufacture.

These thrusts reflect the projected use of composites as the predominant material for future rotor blade construction.

In addition to the advantages already cited for airframe structures, two advantages of composites, peculiar to their application in rotor blades, are:

- The slow, soft failure mode of fiberglass, which gives an aircrew enough warning to prevent catastrophic crashes
- The ability to aerodynamically and structurally tailor a blade to optimize performance, flying qualities, stresses, and dynamic response.

Because of the failure characteristics of fiberglass reinforced composites, more widespread use of these materials can be anticipated. The use of higher modulus materials, such as graphite and boron, will continue to be limited to reinforcing those portions of the blade where increased stiffness is required.

The use of composite materials in the rotor blades of the upcoming generation of helicopter models has increased substantially over previous models. An even greater use on future helicopters is evidenced by the fact that every major Army helicopter contractor has programs under way to investigate composite rotor blades of various designs and constructions.

At present, composite rotor blade production requires complex contoured tooling; hand layup of a variety of fiberglass pieces, contoured honeycomb core, and miscellaneous fittings; a number of subassembly operations; widespread adhesive bonding; and several intermediate oven curing operations.

The development of techniques to reduce the number of operations is needed to reduce costs. This could be accomplished, for example, by combining the development of integrally heated and pressurized production tooling, which would eliminate lengthy oven curing operations, and the development of cocuring techniques to effectively reduce the number of separate joining and subassembly operations.

It will also be necessary to develop and apply a number of quality control and NDT techniques to distinguish between harmful flaws and harmless discontinuities. At present, the use of optical or lead fibers, which, when broken, indicate discontinuities through optical/radiographic techniques; pressurized spars, which indicate discontinuities when leakage occurs; and ultrasonic or "tap" tests do not diagnose the severity and/or location of potentially harmful flaws reliably. Consequently, a number of techniques may be used on a single blade, resulting in excessive costs.

The amenability of composite structures to automated manufacture has been espoused as a major reason for their increased use in the future. However, to date, the application of automation and computer aided manufacture in a production environment has not been extensive. The development of techniques to wind, braid, pultrude, and lay up tape and broadgoods automatically is vital if all-composite structures are to be cost effective.

A summary of some of the typical efforts planned for the next 5 years within the identified major thrust areas, together with the problems they are intended to meet, appears in Table 3.

Drive Systems Need Improved Housings

According to the Battelle study, the major drive system thrusts that the MT program should undertake over the next 5 years are the development of technology for:

- Joining
- Composites
- Quality control and NDT
- Forging
- Computer-aided manufacturing.

Table 3

Important Technical Thrusts: Rotor System

TYPICAL PROBLEM AREAS	THRUST ACTIONS
• High labor content in layup of composite rotor blades • Testing (including NDT) of composite rotor blades requires 20 to 50 percent of manufacturing costs • High cost of multiple curing cycles for composite blades • High cost of nonmetallic blade cores • Joining of blade/root represents a quality problem • Contouring and trimming of blade forms represents high labor costs • High labor content in maintenance of main rotors • High chip losses in machining of rotor hubs • Titanium casting technology not sufficiently advanced to permit application in rotor hubs/components	• Low cost spars from braided/pultruded structures • Application of lower cost core materials • Development of integrally heated blade bonding press • Automatic and semiautomatic tape layup machines for production • Composites with lower curing temperatures • Microwave (RF) curing • Automatic broadgoods layup machines • Standardization of composite materials • Development of in-process inspection systems for assuring adequate joints between components • Diffusion bonding of rotor hub • Development of alternate sources for elastomeric bearings • Continued effort in applying HIP to cast parts to insure quality adequate for critical applications • Improved methods for manufacturing nose caps • Multiple-ram forging of rotor hubs

Helicopter transmissions undergo high stresses that twist and deform the magnesium housings. This allows misalignment of gears and results in wear, failure, and loss of load-carrying capacity. Because of the cascading influence that the housing flexibility has on other problems found in transmissions, a variety of innovative concepts have been proposed to replace the cast magnesium housings.

However, the desire to keep weight down has precluded changing to stiffer but heavier materials. Consequently, efforts to produce stiff, lightweight housings include: boron or graphite/aluminum tubes joined to form truss structures (to provide the bearing surfaces) and covered with graphite/epoxy or sheet metal skins (to retain the lubricant); composite-reinforced metal housings joined by welding segments; and molded advanced composite gearboxes.

Because forgings provide the highest metallurgical quality, their application to highly loaded helicopter drive-system components can be expected to continue. However, the refinement of precision forging methods is necessary to achieve longer life and to reduce chip loss.

Current helicopter gears with extremely close tolerances are expensive to produce. Inspection costs are excessive (more than 10 percent) and rejection rates high (up to 15 percent). Methods to reduce the cost through relaxation of specification requirements and use of "run-in" finish matched gear sets, as well as the application of cheaper in-process quality control and NDT methods, are needed. Such procedures would probably involve the application of computers.

Automation and computer technology may be adapted throughout the producibility trade-off and manufacturing cycle. This might include computer-aided design of advanced, high contact-ratio gears, or the broader application of numerically controlled, high-speed machining operations.

Table 4
Important Technical Thrusts: Drive System

TYPICAL PROBLEM AREAS	THRUST ACTIONS
• Flexibility and nonuniformity of magnesium housings • Seal leakages • High chip losses in machining gears • Current gear materials still lack sufficient resistance to scoring, pitting, galling, and tooth fracture • High maintenance/repair costs • Gear tolerances difficult to achieve • Inspection costs for gears very high • Gears require high finishing costs to provide "super finish" • Assembled shaft gears require numerous fasteners and fittings	• Application of integrally stiffened structures to housings to improve rigidity • Development of improved seals for longer life • Bearing recondition programs • Precision hot forging of gears to minimize chip losses • Modularized construction of housings for improved reproducibility and stiffness • Evaluation of various gear finishing methods and designs for lowest cost yet effective performance • Computer aided inspection of gear forms to reduce costs • Improved gear contour design to increase life • Inertia welding of shafted gears to reduce part count

Table 4 summarizes some of the efforts related to the drive system that Battelle has recommended for the coming 5 years.

Materials, Casting Keys to Turbine Upgrading

The Battelle study identified the following MT thrusts as being the most important for helicopter turbine engines:

- Materials related developments
- Casting
- Joining
- Net-shape processing
- Reducing repair and maintenance.

Turbine engines in the Army inventory have historically experienced periodic increases in power ratings. Turbines using nickel based alloys are already approaching the limits of temperature resistance and expensive cooling systems are required. Thus, application of materials related developments is required to uprate engines further. In these cases, such casting procedures as directional solidification to improve creep resistance of heat resistant alloys are being considered, as are casting of turbine blades with internal/transpirational cooling systems and the casting of advanced high temperature alloys.

From 5 to 20 percent of cast superalloy turbine components must be reworked or scrapped due to nonuniformity of parts or defects found upon inspection. Scrap and rework costs can be reduced by refinement of casting procedures as well as by the application of hot isostatic pressing (HIP), which can preclude up to 90 percent of the castings from being scrapped.

Precision casting in conjunction with HIP is a net shape process that can be expected to eventually replace machined titanium or steel alloy forgings for the compressor section.

Current turbine engines require from 10,000 to nearly 100,000 man-hours of maintenance for every 100,000 flight hours, representing over 25 percent of a helicopter's total maintenance cost. Consequently, efforts to improve upon this record will be emphasized. One method to reduce these repair and maintenance costs is to decrease

Table 5
Important Technical Thrusts: Turbine Engine

TYPICAL PROBLEM AREAS	THRUST ACTIONS
• Solid particle erosion of compressor blading • Bearings are exposed to temperatures approaching limits of materials • Wrought materials require excessive machining to chips • High maintenance/repair costs • High cost of balancing total rotor assemblies • Designing, contouring, and inspecting blades represents a high cost area	• Material conservative processing: Casting T-blades (DS, HIP) Casting C-blades (HIP) Casting stator components Precision forging disks P/M plus HIP of T-disks • Improved coating for blades • Application of heat resistant bearing materials • Improved repair methods: Weld buildup vs blade replacement Diffusion bonding • Computer aided Design Manufacture Inspection • Automated multiplane rotor balance • N/C machining of blisks

the number of parts. This might be accomplished by such procedures as joining of disks and shafts other than by bolting or eliminating complex brazed structures.

Nearly 60 percent of all unscheduled engine removals in Southeast Asia were the result of erosion and foreign object damage. This suggests the appliction of improved materials for coating blades, as well as the repair of damaged compressor wheels through the joining of replacement blades.

Some of the typical problems experienced with turbine engines, as well as potential actions to resolve them, are summarized in Table 5.

Producibility Enhanced

In conclusion, the helicopter manufacturing state of the art has already advanced substantially in preparation for the full-scale production of the new generation of Army helicopters. The accomplishments of the Aviation MT program have had a significant effect on improving the producibility of a number of their components. Over the coming years, more generic classes of problems impacting helicopter cost and performance will be attacked. However, primary emphasis will remain on applying the results to Army requirements. Funded at a higher level over the next 5 years, the AVRADCOM program should provide a great impetus to continuing improvement of helicopter manufacturing technology.

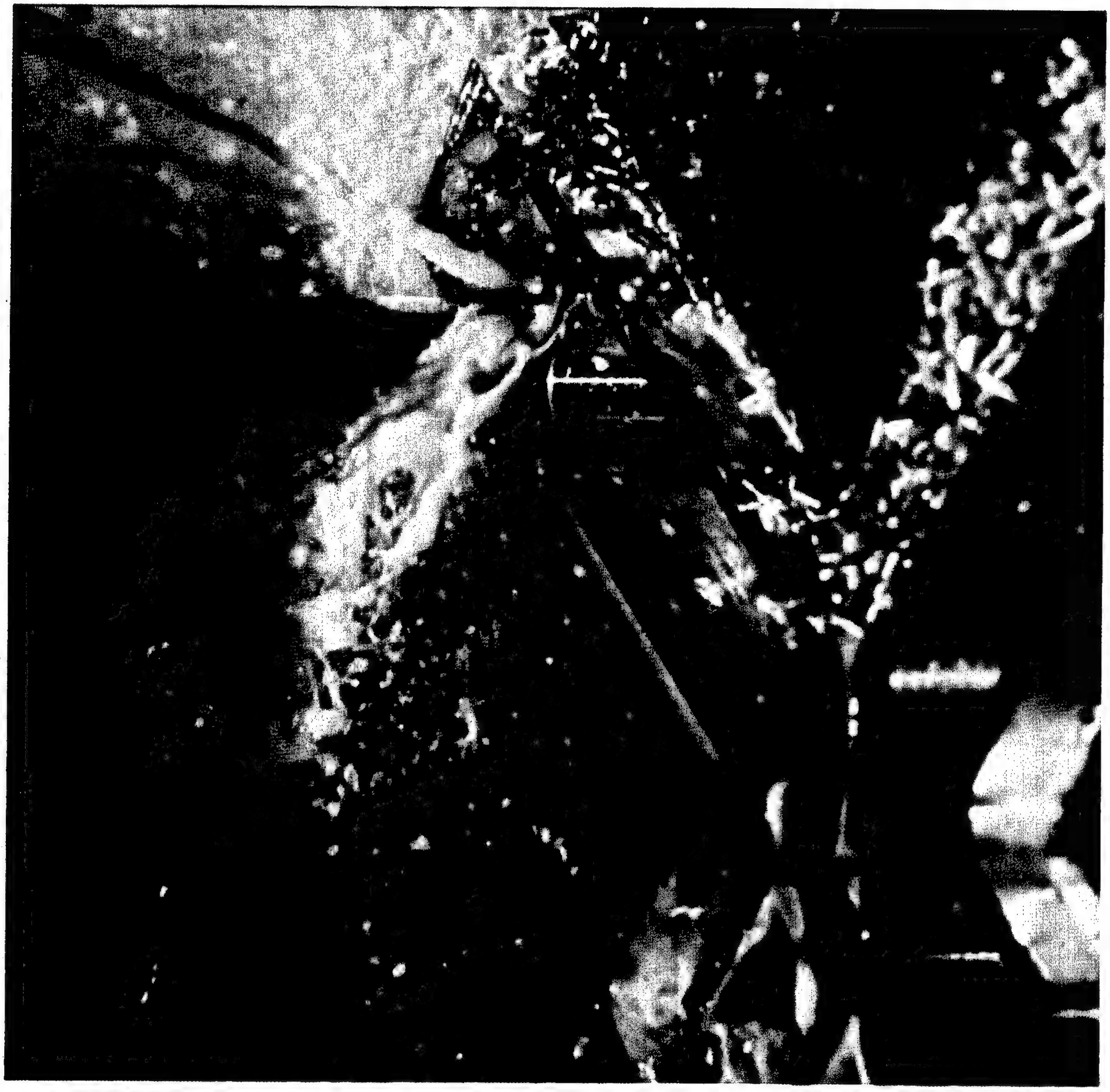
Part 1 of this series appeared in Vol. 2, No. 1, of the **U.S. Army ManTech Journal** and Part 2 appeared in Vol. 2, No. 2. The first article highlighted manufacturing improvements and cost savings in helicopter airframes and rotor systems. Part 2 focused on savings resulting from advanced drive system and turbine engine technology.

US Army

ManTech Journal

Conferences An Effective Means

Vol. 2/Number 4/1977



US Army
ManTech Journal

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Contents

ABOUT THE COVER:

Typical ultrahigh speed deep center bore seen in this photograph is an action example of the new technology developed for the Trident I missile production. Designs of several metallic parts for the Trident I missile required deep pocket milling and thin wall machining with minimum distortion and low residual stresses. This unclassified sample demonstrates the new technology in process, providing a surface quality that does not require further finishing operations. (Courtesy of Lockheed Missile and Space Company.)

Comments by the Editor

DR. JOHN J. BURKE

The subject of metal chip removal covered in this issue of the Army ManTech Journal is without a doubt one of the most important of all activities in an industrial nation such as the United States. When one considers the impact on our lives of the resources in materials, man-hours, fuel, and facilities that are expended in removal of excess metal during fabrication, it clearly can be seen why both the military services and industry are devoting so much attention toward making the processes involved more efficient.

The DOD/Industry Metal Chip Removal Conference was a positive first step in bringing the two types of activity together to mount a joint effort toward reducing inefficiencies in the processes of removal. At this conference, a remarkably cooperative attitude generated a clear understanding of the problems involved and pinpointed a vast array of positive paths for their solutions. The conference may become a landmark in the future, guidelining effective means for approaching and handling so large and universal a challenge as that posed by chip removal in fabrication. The Department of Defense, the military services, and industrial leaders should be complimented on their grasp of this challenge, its scope and magnitude, and its universality in regard to both military and commercial production. The results of the conference are most impressive, and we look forward to many exciting developments in the future as these projects bear fruit.

This issue of the Army ManTech Journal also outlines the U.S. Navy's program on manufacturing technology, one which has produced significant advancements already and will be a program for all those engaged in this effort to watch, especially in the area of electronics, large structures, and the all important maintenance aspect.

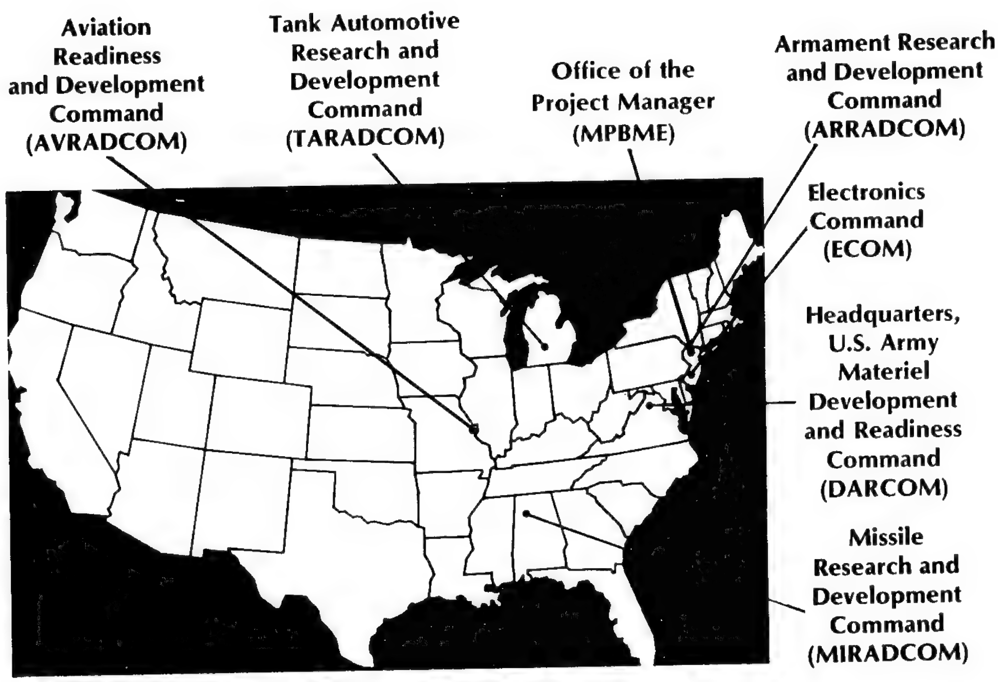
Producibility is an area in which the Lockheed Company has taken a great interest, as discussed in the article on their reproducibility team. Integrated engineering/management is certainly a wave of the future on the manufacturing scene, as has been highlighted in several past issues of this magazine. Other significant developments in ultrahigh-speed machining, microdrilling, cutting fluid advancements, and the compilation of useful machining data round out the topics in this issue highlighting chip removal. We hope these articles will provide new insights among our readers into means for improving their own metal removal operations.

The next upcoming issue of the ManTech Journal will feature the Aviation Research and Development Command and its manufacturing technology program, a program of

far-reaching impact. Composites will be a primary topic among the articles forthcoming in that issue, as would be expected; also, several innovative techniques involving some unusual materials will be covered. A large section on brief status reports will be a special feature, as will an article on group technology by the well-known Dr. Inyong Ham of Pennsylvania State University and Doug Ross of Softech. They were prime contributors to the Air Force's ICAM report, which was completed earlier in 1977 following an intensive study on the subject of group technology and its relationship to productive practices here in the United States.

Subsequent issues in 1978 will cover the topics of materials testing, casting, and joining. These issues of the ManTech Journal will discuss new developments in the Army and also in industry for those particular areas of activity. The field of materials testing, or quality assurance, is rapidly changing the processes followed for many years in our manufacturing activities, with many of the new techniques providing startling control of product quality. We think our readers will be pleasantly surprised at some of the advancements discussed in these forthcoming articles.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



RAYMOND L. FARROW is Chief Technology Transfer Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts. He holds an A.B. Degree in Physics from Clark University, an M.B.A. with honors from Boston University, and was selected as a Sloan Fellow at the Stanford University Graduate School of Business. In addition to extensive technical and managerial experience, he has served as Staff Advisor to the Director and as Technical Assistant in the area of program development. Mr. Farrow has worked extensively on the development of the SPIDERCHART management concept and has served as a consultant to government and industry in the area of R&D management and economic planning. He is currently responsible for assisting the DARCOM Office of Manufacturing Technology in the management of the Army MT program, serves as Assistant Editor of the U.S. Army ManTech Journal, and most recently served as Executive Secretary of the DoD/Industry Metal Chip Removal Conference. He is a member of Beta Gamma Sigma, the North American Society for Corporate Planning, and the American Defense Preparedness Association.

Chip Removal – An Investment Opportunity

Tri-Services, Industry to Cooperate

With the ever increasing demand for new and expanded federal programs, financial resources within DoD have become severely limited. Coupling this with increasing weapons system sophistication and the everpresent inflation factor, reducing production costs becomes a major objective of the DoD Manufacturing Technology Program. Return on investment has surfaced as a major ingredient in the analysis of projects and in the final investment decisions. In addition, the Manufacturing Technology Program serves as a means for addressing those problems which, when solved, can result in reduced capital investment requirements, shorter production lead times, reduced use of our critical resources, and also improved productivity and reliability of our materiel.

The Air Force Materials Laboratory sponsored an Air Force/Industry Manufacturing Cost Reduction Study in the Fall of 1972.* A group of over seventy key management and technical specialists, representing several Air Force organizations and over twenty-five industrial firms, had as their objective definition of the cost of major airframe and aeropropulsion structural components and determination of best approaches for end item cost reduction while maintaining reliability and performance. Among the results of their study was that "the most obvious area for cost reduction was improvement in metal removal". Specific conclusions highlighted in the Executive Summary of this study** state that "as much as 90 percent of increasingly expensive and scarce engine and airframe materials can end up as chips". Overall engine/airframe cost reductions of up to 10 percent are predicted if the problems in metal removal are solved.

Need for Conference Seen

Following the initiatives for cost reduction set forth in April 1975 by then Deputy Secretary of Defense W. P. Clements, it was evident that DoD should conduct a joint DoD/ Industry "Chip Removal Cost Reduction Conference". A prior estimate indicated

that the U.S. spends over $60 billion per year removing metal during the process of fabricating metal parts.***In November 1976, an analysis of the DoD Manufacturing Technology Program showed that 20 percent of the effort was dedicated to metals, and of this only 5.9 percent to metal removal. It is apparent that since only 1.2 percent of the current MT program was related to metal removal, even a small improvement in this area could have a substantial impact in providing cost reduction benefits for military materiel.

As a result, Mr. John J. Bennett, Acting Assistant Secretary of Defense (Installations and Logistics), requested the Army to arrange and coordinate a joint DoD/Industry Chip Removal Cost Reduction Conference. Held in February 1977, this conference identified many areas of investment opportunity.

Over 190 Tasks Spotlighted

Recognizing the valuable input to be obtained from outside the DoD environs, panels of industrial and academic experts were formed. Potential DoD problem areas were identified, collected, and widely distributed as initial guidance to the metal removal community. Consistent with the chip removal process, panel experts reviewed the problems and potential solutions in the areas of cutting tools, cutting fluids, machine tools, materials, management strategy, and the alternatives of net shape and other processes. Over 190 potential solutions requiring almost $200 million of investment have been studied in depth by both government and industrial leaders. The SPIDERCHART in Figure 1 shows those areas in which investment opportunities have been identified.

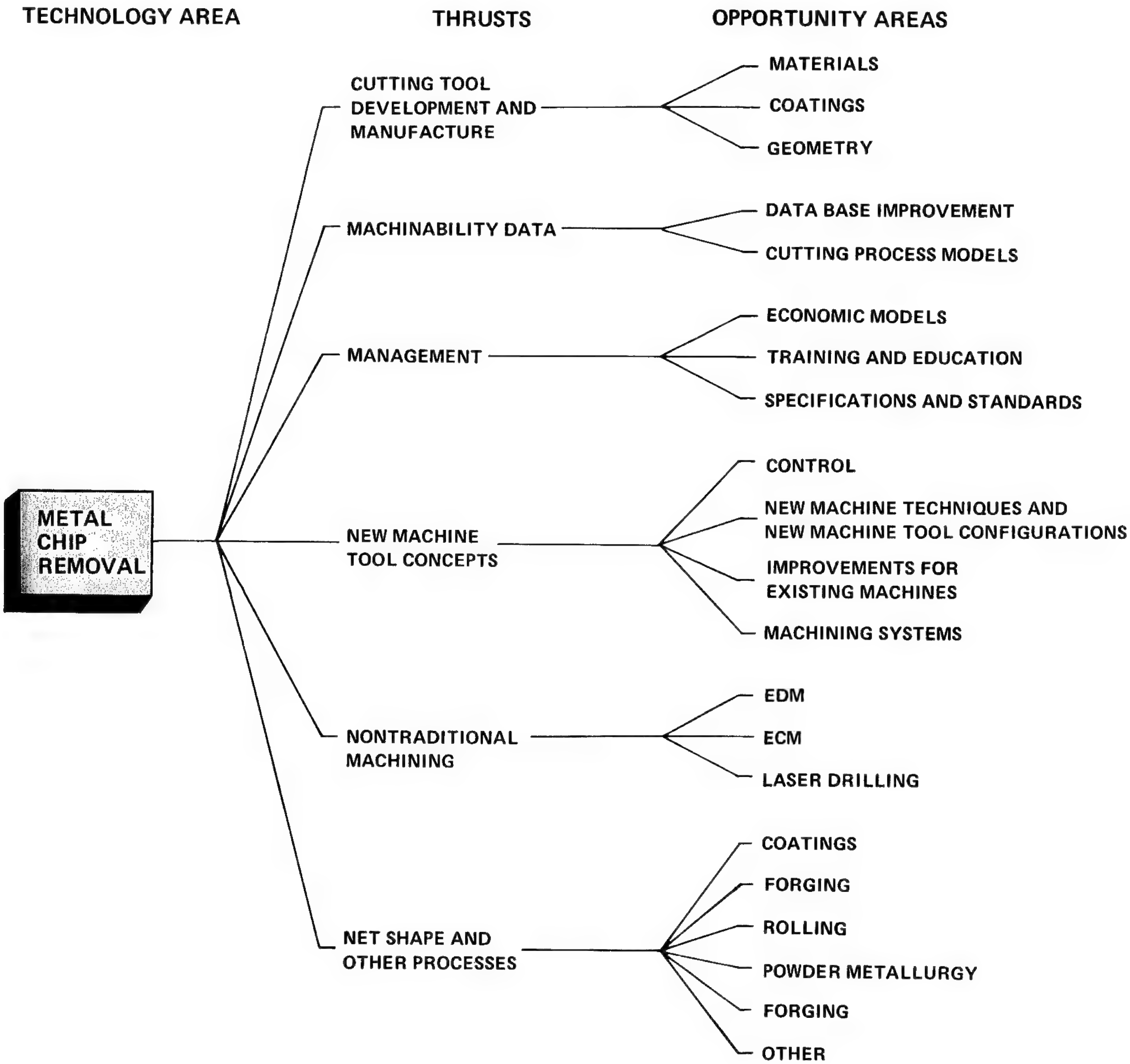
Specific major recommendations which have been cited include

- Development of Machineability Data
- Implementation of Performance Specifications for Procurement of Cutting Fluids
- Improved Drilling Techniques for Fastener Holes
- Establishment of High Speed Machining Techniques
- Initiation of Comprehensive Programs for Machining Processes to Include Machine Tools, Process Controls, and Sensor Development
- Application of Adaptive Controls, Process Analysis, Economic Modeling, and Machine Diagnostics
- Application of CAM to Planning, Scheduling, and Control and Establishment of MIS Feedback Data
- CAD/CAM Interface

National Impact Significant

Analysis of individual projects which have been proposed to address the high cost of metal removal shows that literally millions of dollars can be saved with relatively small investments. In the area of cutting fluids alone, substantial dollar savings await only a minor injection of manufacturing technology effort. Considering the numbers of machine tools (estimated at approximately 3,000,000 by the American Machinist 11th Inventory) as well as cutting tools, any improvement which reduces their costs or increases their lives is bound to have a significant impact not only on the DoD but on our national productivity base as well.

As an example of prior benefits from the DoD Manufacturing Technology Program in the metal removal area, we can look to a project to apply coolant chip ejector drilling to howitzer recoil mechanism components. Investment in this effort has resulted in drilling rates 1.6 to 30 times faster than conventional methods as well as elimination of stress relieving heat treatments and straightening operations. This not only reduced time and manufacturing costs, but eliminated scrap. In a similar vein, a manufacturing technology project to alloy new processes for rapid boring of gun tubes has cut boring time from 3.9 to 2.4 hours on the 105-mm gun tube. This has been achieved by a DoD investment of only $50,000. Numerous additional examples from each of the services could be given to attest to the benefits received from the DoD Manufacturing Technology Program. A compilation of many of these DoD efforts is provided in the form of the Machining Data Handbook—a joint effort of the U.S. Army and the U.S. Air Force Materials Laboratory. Savings in excess of $300,000 per year for the Army alone have been estimated—even greater levels of return on investment are an obvious result of the DoD manufacturing technology investment.



METAL CHIP REMOVAL INVESTMENT OPPORTUNITIES

FIGURE 1

Conferences An Effective Means

Conferences such as the Air Force Cost Reduction Study, the DoD Chip Removal Conference, and the several Army Manufacturing Technology Assessment Studies have served to sensitize both DoD and Industrial leaders to the importance of investments in this area. Current plans call for a total tri-service metal removal manufacturing technology investment of over $5.5 million in FY79—significantly increased over the less than $1.5 million for FY78. For the next five year time frame, a $26-32 million program is forecast for this area—representing 13 percent of the metals funding. This is more than double the current level of effort, with substantial programs directed at aircraft, missiles, weapons, ammunition, and land vehicle systems.

As further recognition of the importance of this area, the Army has established the Army Metal Removal Working Group to advise and coordinate projects in this area. However, the desired results cannot be accomplished by DoD alone. We can invest seed

money. We can provide incentives. We can offer technical assistance. But the users of the technology must themselves make it work. The DoD/Industry team together must accept the challenge and work together to implement new technologies, to lower costs, and to increase our national productivity to ensure maximum weapons systems acquisition with our limited resources.

Chip removal **is** an investment opportunity!

Acknowledgements

It is evident that conferences such as the DoD Metal Chip Removal Conference require extensive efforts on the part of a few dedicated DoD personnel. Mr. Gordon Ney, U.S. Army Industrial Base Engineering Activity, Chairman of the DoD Manufacturing Technology Advisory Group Subcommittee on Metals, Mr. William A. Harris, U.S. Air Force Materials Laboratory, and Mr. William A. Welch, U.S. Naval Material Industrial Resources Office have served as the basic Review Committee to analyze the DoD Conference results and provide a coordinated plan for future service investments. Their efforts are truly appreciated by all of us who will depend on these results for future actions.

*Summary of Air Force/Industry Manufacturing Cost Reduction Study, AFML-TM-LT-73-1, Manufacturing Technology Division, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio.

**Executive Summary of the Findings of the Air Force/ Industry Manufacturing Cost Reduction Study, June 1973.

***Source: American Machinist 11th Inventory.

CAPTAIN LOUIS C. DITTMAR, USN, is Director of the Navy's Manufacturing Technology Program. He entered the Naval Academy from West Virginia in 1947. He graduated in 1951 and spent one tour at sea on an escort carrier, the U.S.S. SIBONEY, before going through the Flight Training Program. After receiving his wings he flew the A-1 Skyraider attack aircraft with various West Coast squadrons and on one tour with the Vietnamese Air Force 23rd Wing at Bien Hoa Air Base. For his last three year sea tour he transitioned to the twin jet A-6 All Weather Attack aircraft, and while serving as Executive Officer and Commanding Officer of Attack Squadron 196 served two more tours in Vietnam. He spent one tour ashore as an Instructor at the Naval Academy. After a year at the Naval Postgraduate School he served in a Material Aquisition billet with the Navy office at Lockheed Missile and Space Company in Sunnyvale, California in the Polaris and Poseidon programs, and later had a tour as the A-6 Class Desk Officer at the Naval Air Systems Command. Just prior to his current assignment he spent four years with the Joint Strategic Target Planning Staff at Offutt Air Force Base in Omaha, Nebraska.

Optical Avionics, Automatic Frame Bender

Navy Saves Costs Via MT Program

With a production and procurement program that exceeds $16 billion annually, the U.S. Navy recognizes the value and benefits to be gained from an aggressive and forward looking Manufacturing Technology (MT) program. Consequently, the Navy has increased the funding of a visible, clearly identifiable MT program featuring centralized management.

As an example of the savings available, a current program to develop a computer controlled frame bender for ship construction offers potential savings of $6 million per year in labor costs. In another program, a fiber optics data link system has been demonstrated in the A-7 aircraft. The fiber optics allow savings in annual operational costs of more than $10,000 per aircraft, plus savings in procurement costs of $6,800 per aircraft.

Thus, the program is already successful—and it has support from the top. With the Navy facing the prospect of increasingly complex and sophisticated weapons systems, the Chief of Naval Material has stressed the importance of developing new techniques to reduce acquisition and life cycle costs. That's what the MT program is all about.

Industry is constantly seeing many important and exciting advances in manufacturing technology. With proper development and application, these advances will provide increased productivity along with lower costs. The Navy regards the MT program in this light—a means for reducing costs by utilizing advanced technology. Through continuing liaison with knowledgeable industrial personnel, the MT program closely monitors this exploding technology. New techniques thus are developed and then integrated into the Naval production and procurement system.

Management Control

Central management of the Navy MT program resides in the Office of the Director of Manufacturing Technology under the Chief of Naval Material (for Acquisition). This office guides policy, develops long range goals, and prepares and controls the budget. Each of the major hardware commands (Air, Sea, and Electronics) also has its own Manufacturing Technology organization. These offices relate to the Office of the Director and are responsible for carrying out the program within their own spheres of interest. This responsibility includes preparing MT project proposals, formulating the budget, and conducting projects and reporting on their progress.

In addition, the Naval Material Industrial Resources

Office (NAVMIRO), an arm of the Naval Material Command staff, performs technical review, technical coordination, and administrative functions in support of the Director of Manufacturing Technology. The Navy MT organization is shown in Figure 1.

The Navy's philosophy on technology development has an important impact on its MT program. The Navy believes that government funds should be applied only to ease the transition of technology from R&D into industrial applications, not to replace industrial sector investment. Therefore, Navy MT investment intercedes only where risk is high, but where predicted payoff in future Navy procurement is strongly indicated.

Investment Opportunity Studies

A major thrust of the Navy program is the reduction of acquisition costs. Toward this end, several investment opportunity studies are under way to identify factors that tend

U. S. NAVY MANUFACTURING TECHNOLOGY ORGANIZATION

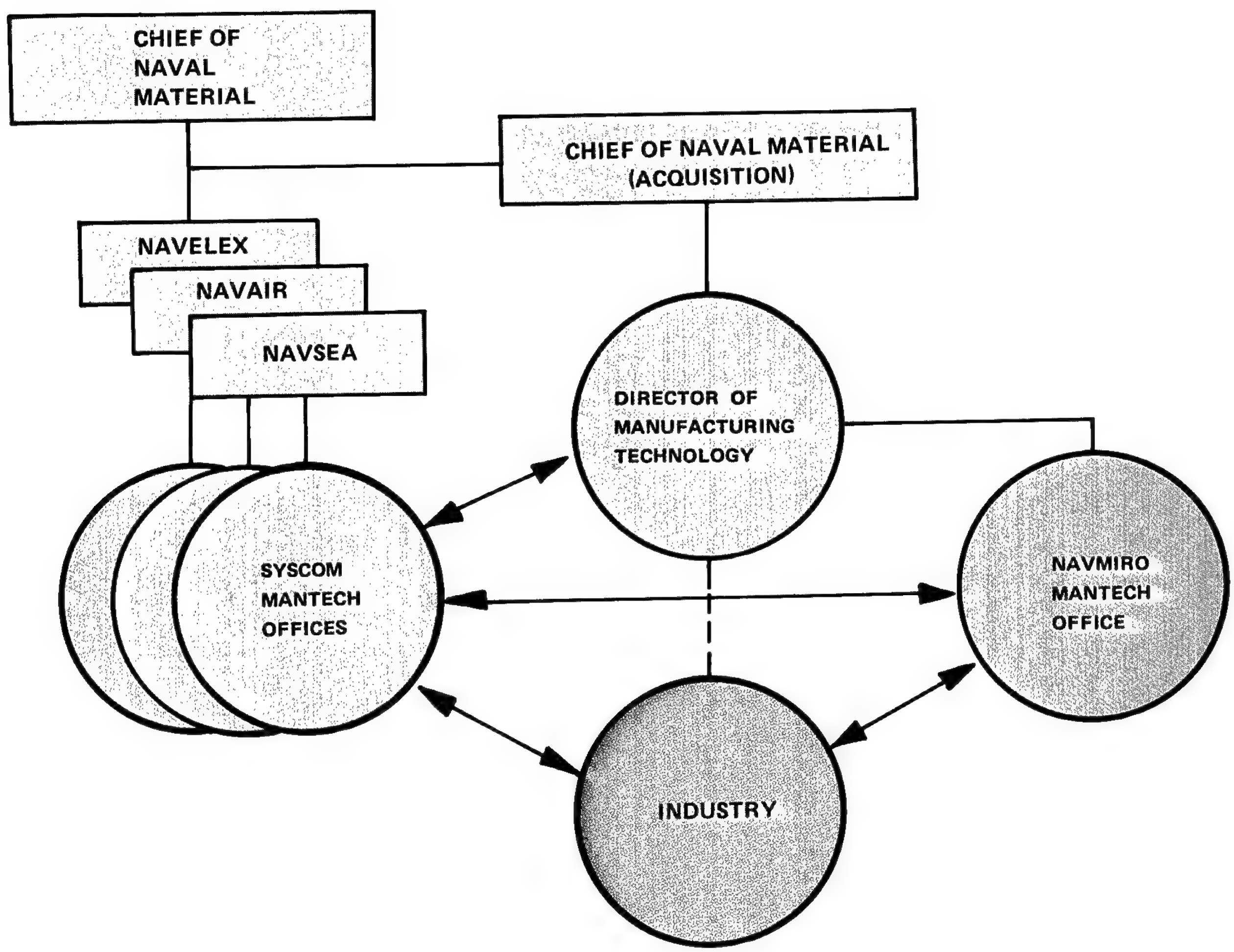


Figure 1

to drive the costs of naval material upward. The studies cover procurement and manufacturing processes in the areas of new aircraft construction, aircraft overhaul, ship construction and overhaul, electronics, and weapons systems. At the same time they identify cost drivers, these studies will establish the framework for projects aimed at providing solutions to the manufacturing problems identified. They will also provide the Navy with realistic information that will help in developing long range technology plans.

The Navy has established steering committees to initiate, monitor, and guide these studies, drawing committee members from the pool of Navy personnel with knowledge and expertise in each area of study concern.

Electronics

Looking at specific study areas, an Electronics Cost Driver Study was completed in June 1977. The study examined investment opportunities in manufacturing technology related to electronics systems procurement. The major cost areas for electronic products were determined by a study of a detailed breakout of electronics subcomponent and labor categories. Cost data were obtained from 58 Navy and industrial offices on approximately 100 systems, which represent a broad spectrum of Navy electronic procurement. Results indicate that the product costs are divided evenly between material and labor categories.

In addition, costs were broken out for electronics manufacturing process areas such as volume of production, capital equipment, and manufacturing methods. Consideration of process and product factors provided an effective means of evaluating ninety-nine candidate projects to ensure program balance.

An economic analysis considered present value costs and savings for the candidate projects. Technical evaluations of the projects allow risk factors to be assigned. The analysis, based on a five year payback period, shows an average savings to investment ratio of up to twenty to one. A prioritized manufacturing technology plan was generated based on this data.

A final report on the study makes recommendations for near term improvement of the plan and suggests incentives required to stimulate industry participation in the FY82-84 time period. Implementation of the study is scheduled to start in FY79.

Ships

The Ship Study will encompass two significant areas—new ship construction and ship overhaul. The objective of the Ship Overhaul Study is to reduce the cost of fleet maintenance. The study team will examine the ever increasing costs in this complex and controversial area in two steps:

(1) Identification of the high cost areas in ship overhaul
(2) Examination of these areas for MT investment opportunities.

Study of new construction will be conducted with support from several commercial shipyards that are active in Navy shipbuilding. These shipyards will provide a man-hour data base for each type of ship being built. This data will be placed in a matrix format indicating the number of man-hours required by each ship category to perform the various manufacturing operations. From this data base, the shipyard contractors will identify the high cost areas, investigate the processes involved, and determine where MT efforts could substantially reduce costs. A coordinating contractor will review the man-hour data, individual contractor reports, and other available information and prepare a final report that will provide MT investment direction.

Aircraft

The Aircraft Manufacturing and Overhaul Cost Driver Study was initiated in February as a two phase effort—manufacturing and overhaul. The manufacturing phase, which is concerned with the identification of the high cost areas in aircraft manufacturing, is being conducted by a Naval Air Systems Command work study team in conjunction with a contractor. A final report containing the rationale, technical data, and the high cost areas is scheduled to be completed in February 1979.

The overhaul phase is being conducted by a work study team comprised of Naval Air Rework Facility personnel. This team, in conjunction with a contractor, will develop a data base that correlates component manufacturing activities with major existing aircraft systems. The overhaul study will determine how well manufacturing functions selected describe those performed at the depot and intermediate maintenance levels and how these interact with the repair or overhaul of major aircraft systems.

The high cost elements that are identified will provide a data base for the application of Manufacturing Technology projects that will be reflected in reduced life cycle costs. The final report is scheduled for completion by December 1978.

Emphasis will be on programs that affect the Navy most in future years. Although different manufacturing procedures are used by different companies, the results of the study should provide a more uniform approach to manufacturing and overhaul.

Weapons Systems

The Weapons Study covers two weapons categories: air launched and sea launched. The air launched portion is being administered by the Naval Weapons Center, China

Lake, and the sea launched portion by the Naval Surface Weapons Center, White Oak. Types of weapons systems to be considered include missiles, torpedoes, mines, guided projectiles, and aircraft guns.

A portion of the air launched phase was undertaken by a contractor who coordinated and analyzed the missile cost data available at China Lake. Only missile systems were considered since it was found that they would contain the highest cost drivers in the weapons area. The data reviewed encompassed Shrike, Sidewinder, Phoenix, and Sparrow missiles. The Cruise missile will be studied later.

Liaison with other studies conducted by the Navy, Army, and Air Force has allowed comparisons with similiar data. Development of a generic work breakdown structure provides cost identification and the maximum correlation of available data. Cost drivers were identified by standard components, such as motor case, nozzle, and liner.

The Naval Surface Weapons Center has prepared a procurement package to initiate a nine month effort on the air/sea launched phases of the study. This contract was awarded in March 1978. Coordination with industry will be an essential element to the success of the study.

At the completion of the weapons study in early 1979, a conference is planned to outline study results. Industry will then be requested to submit MT project proposals for incorporation in the Navy's five year plan.

The Navy is confident that examination of the results of these cost driver studies and full implementation of the Manufacturing Technology Program plans that evolve will result in significant productivity improvements and cost reductions. These results will contribute to the strengthening and maintenance of a modern industrial production base.

The Navy MT programming reflects increased investment planning as the program moves into the future. In the current fiscal year, much of the effort is concentrated in the areas of electronics, metalworking, and nonmetallic materials.

Current Projects

The computer controlled frame bender for ship structures is one example of a current project with high productivity potential. The bending and shaping of large frame beams and plates is, at present, a significant cost factor in ship construction. The estimated cost for manual bending of frame beams is $230 per bend. Since each bend is unique, repeatability is improbable, if not impossible. On

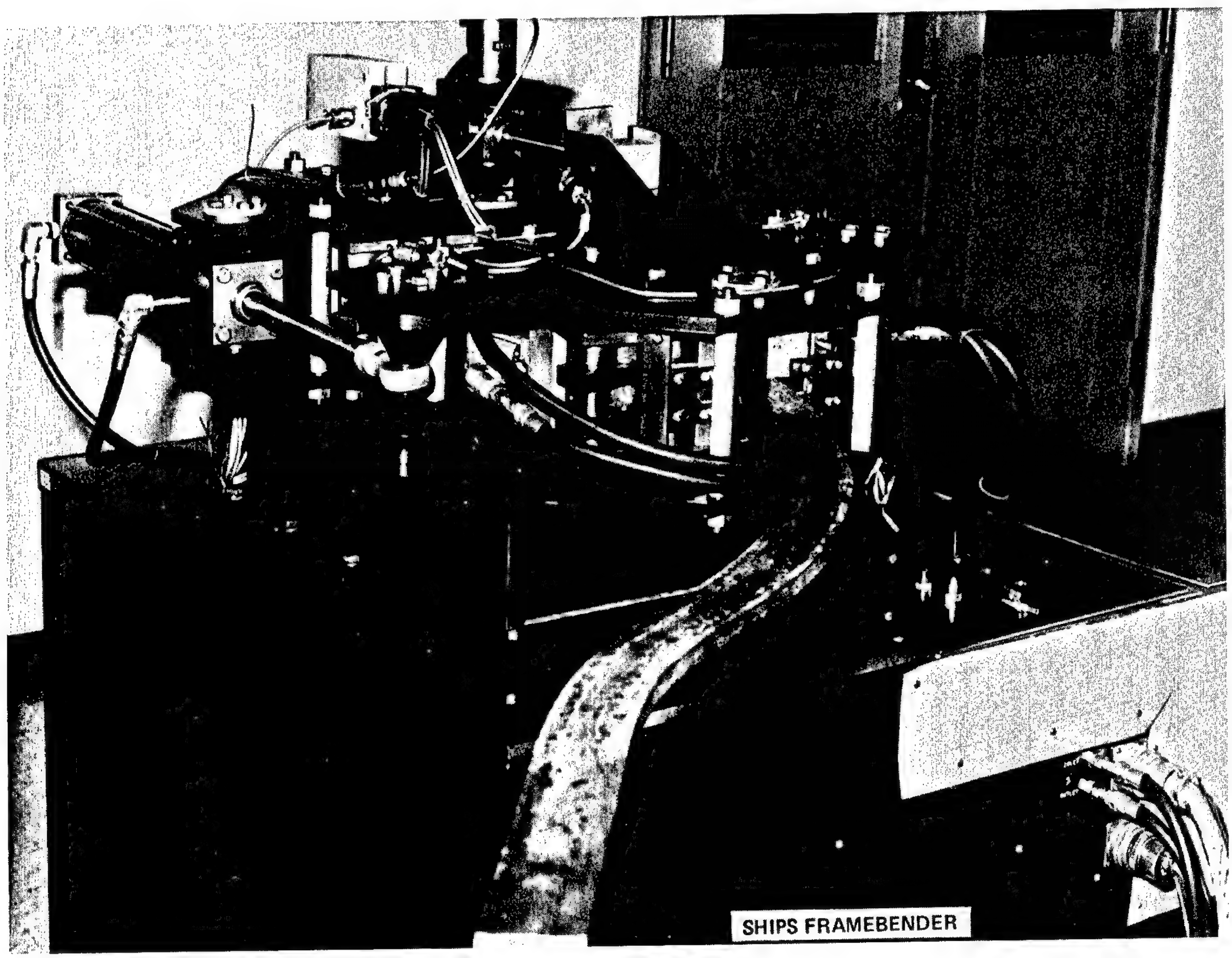


Figure 2

destroyer tenders, or ships of comparable configuration and size, there are approximately 4500 frames per ship. The magnitude of the labor and cost is readily apparent.

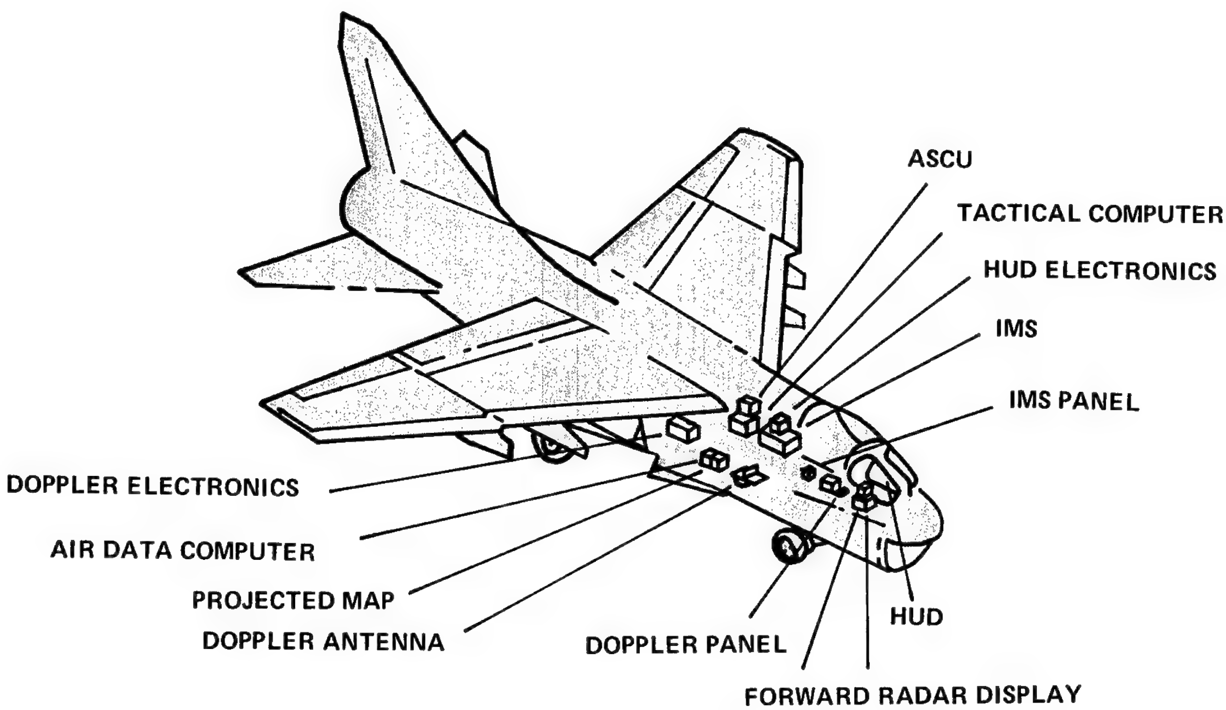
Under a grant from the National Science Foundation, an experimental computer controlled, cold working, multiaxis frame bender (Figure 2) was built and tested. Using Navy MT seed money, a production scale frame bender will be fabricated and evaluated for operation at a commercial shipyard. It will be used to form frame beams for destroyer tenders and oilers currently contracted for construction. The estimated savings in labor on construction of these ships when implemented will be approximately $6 million. Additionally, the system should allow greater reproducibility and, consequently, improved ship fitup procedures, thus improving ship structure quality.

Fiber Optics is another example of an emerging technology with high potential. Traditionally, fiber optics technology has been used primarily for light transmission, e.g., decorative home lighting and panel indicators for remote lighting. Today, there is a concentrated effort by both industry and government to use fiber optics technology in transmitting electrical signals. Basically, fiber optic links operate by transforming electrical signals into optical signals by light emitting diodes (LEDs) or laser diodes. The optical signals may then be transmitted via the fiber optic lines. The optical signals impinge on photosensitive elements, such as photodiodes, which transform the optical signals back into electrical signals.

The Navy has completed the testing of a fiber optics data link system on an A-7 aircraft. Several of the avionics systems have been converted to fiber optics.

Fiber optics transmission (Figure 3) provides an attractive alternative to the use of wire and offers both weight and cost advantages. In the A-7 test system, the cable and connector weight has been reduced from 82 to 3.6 lb. This is equivalent to an annual operational cost savings of more than $10,000 per aircraft. Additionally, there is a corresponding procurement cost saving of $6,800 per aircraft. The materials used in the manufacture of fiber optics are readily available and noncritical.

Other benefits of fiber optics transmission are faster, safer, less vulnerable, and more versatile signal and data linkages. These attributes will take on increasing significance as advanced weapons delivery systems are accepted—systems in which invulnerability to electromagnetic interference is mandatory and increased use of advanced composite structural components will be more prevalent.



N/WDS BEFORE AND AFTER

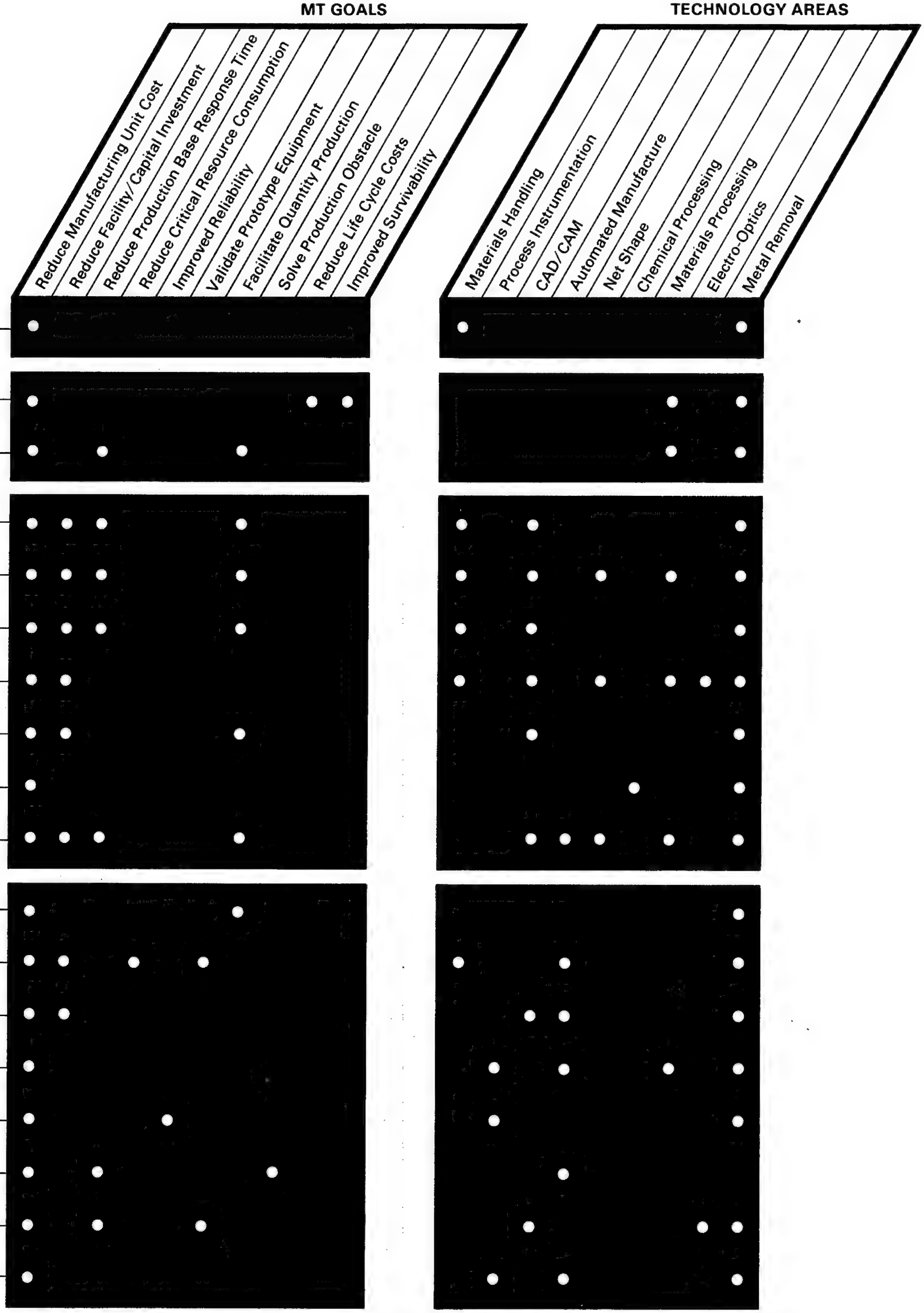
	WIRE	FIBER OPTICS
NUMBER OF CABLE	302	13
TOTAL LENGTH	4832′	260′
TOTAL CABLE & CONNECTOR WEIGHT	82 LB	3.6 LB
TOTAL PARTS COST, CABLE/CONNECTOR		1.1 K

US ARMY CHIP REMOVAL MM&T PROGRAM

MM&T PROGRAM — **THRUST** — **PROJECT**

- CUTTING TOOL DEVELOPMENT AND MANUFACTURE
  - OPTIMIZATION OF STEP THREAD TOOLING
- MACHINABILITY DATA
  - MACHINING METHODS FOR ESR 4340 STEEL
  - IMPROVED AND COST EFFECTIVE MACHINING TECHNOLOGY
- MANAGEMENT
  - AUTOMATED PROCESS CONTROL FOR MACHINING (CAM)
  - GROUP TECHNOLOGY OF WEAPONS SYSTEMS
  - APPLICATION OF GROUP TECHNOLOGY FOR ROCK ISLAND ARSENAL MANUFACTURING
  - GROUP TECHNOLOGY AND CELLULAR MANUFACTURE FOR FIRE CONTROL COMPONENTS AND ASSEMBLIES
  - ESTABLISH MACHINE TOOL PERFORMANCE SPECIFICATIONS
  - ESTABLISH CUTTING FLUID CONTROL SYSTEMS
  - SIMULATION OF AMMO PRODUCTION LINES
- NEW MACHINE TOOL CONCEPTS
  - MANUFACTURING METHODS FOR HIGH SPEED MACHINING OF ALUMINUM
  - USE OF ULTRA-HIGH SURFACE SPEEDS FOR METAL REMOVAL FOR ARTILLERY SHELLS
  - FLEXIBLE MACHINING SYSTEMS PILOT LINE FOR TRACKED COMBAT VEHICLE COMPONENTS
  - CLOSED LOOP MACHINING FOR AIRCRAFT MID FRAME
  - APPLICATION OF CONTROLLED-FORCE MACHINING
  - PRECISION MACHINING OF OPTICAL COMPONENTS
  - MODIFIED RIBBON RIFLING GENERATING MACHINE
  - SIMPLIFICATION OF BREECH RING MANUFACTURING AND HANDLING

SPIDERCHART


MT GOALS
Reduce Manufacturing Unit Cost
Reduce Facility/Capital Investment
Reduce Production Base Response Time
Reduce Critical Resource Consumption
Improved Reliability
Validate Prototype Equipment
Facilitate Quantity Production
Solve Production Obstacle
Reduce Life Cycle Costs
Improved Survivability
TECHNOLOGY AREAS
Materials Handling
Process Instrumentation
CAD/CAM
Automated Manufacture
Net Shape
Chemical Processing
Materials Processing
Electro-Optics
Metal Removal

Savings Built Into Design

Reproducibility Tean

TOM F. VAJDA is Manager of Manufacturing Technology Division with the Lockheed Aircraft Corporation, Missile Systems Division, Sunnyvale, California. During his 24 years with Lockheed he has been Manager of Tooling at the California Division, Chief Manufacturing Engineer for the Lockheed Electronics Company in Plainsfield, N.J., and Manager of Electronics Production at the Missile Systems Division in Sunnyvale as well as Manager of Production Control and Mechanical Manufacturing Engineering. Prior to joining Lockheed, he was a Chief Design Engineer with the Hughes Aircraft Company on the Falcon missile. Mr. Vajda has a Bachelor of Arts degree in Psychology from the University of Southern California and served as a pursuit pilot in World War II. He is a registered Professional Engineer in the State of Illinois and a member of the American Society of Tool and Manufacturing Engineers. Mr. Vajda has written numerous technical papers and has several patents to his credit.

ALBERT REED has developed, written, and coordinated the publication of diversified technical communications for industry and government for the past 27 years. With Lockheed Missiles and Space Company he has spent 12 years as a Publications Engineer Specialist writing, coordinating, and supervising the preparation of technical manuals on the operation and maintenance of Polaris and Poseidon missile systems. The past five years were concerned with studies and programs assigned to the Advanced Manufacturing Technology organization. His numerous assignments included the compilation of the four volume Trident I Manufacturing Development Plan, the preparation of Fleet Ballistic Missile system and new business proposals, the planning and establishment of resource controls, and assisting Missile Systems Division management with presentations, planning, and publications. Mr. Reed has an AS, Supervisory Management (1976), Foothill College; an Industrial Relations Certificate (1968), University of California (Berkeley); and a Certificate in Diesel Engine Design and Maintenance (1947), Hemphill Diesel Engine School. He has completed courses in Electronics, Computer Programming, Proposal Management, and Contract Administration.

By bringing a manufacturing reproducibility team into the design process, Lockheed has incorporated significant savings in the Trident I missile production process, while improving part repeatability. At the same time, much needed savings in weight and space have been realized.

The high performance operational requirements of the Trident I SLBM (submarine launched ballistic missile) created severe new manufacturing problems at the Missile Systems Division (MSD) of Lockheed Missiles and Space Company. Major design problems on the Trident centered around space and weight constraints.. The problems were compounded by rigid contractual budget and time constraints.

Goals on the program of the Missile Systems Division were to maximize the producibility and repeatability of manufactured items and to produce better products at lower costs. To accomplish this, they formed a producibility team—led by manufacturing personnel—to implement and coordinate the design engineering, product assurance, manufacturing, and materiel functions throughout the missile design and manufacturing planning process.

Initially, the team identified manufacturing technology voids in light of system design. The problem then became one of identifying and developing techniques to fill these voids and enable quality hardware production on schedule and at target cost. The major technology areas identified and developed included microelectronics, electronic packaging and assembly, advanced manufacturing systems, reentry materials and processes, composite structures, and metal removal.

The SPIDERCHART in Figure 1 shows the imaginative,

ackles Trident

creative approaches successfully developed and introduced for the routine production of exceedingly complex Trident I hardware in each of these key technology areas.

Producibility Team Key to Effort

The producibility team members were dedicated to providing cost effective, reliable, and producible hardware. Their function was to evaluate designs and consider standardization of fabrication processes, assembly techniques, tooling, inspection attributes, and testing systems. That is, they sought to combine optimum design with optimum production processes.

Bringing the producibility team in early in the development process helped to meet the design to cost objective with repeatable, reliable hardware. Systems were designed with manufacturing technology in mind—and manufacturing planning was done during the design process. In other major programs before the Trident I missile effort, manufacturing technology was not considered until designs were firm. This approach precluded manufacturing influence on design, created hardships on manufacturing and production control, and led to high tooling costs.

The producibility team approach, on the other hand, insures the necessary close coordination among the design engineer, manufacturing engineer, quality engineer, and other engineering participants. It was initiated by assigning a knowledgeable and responsible specialist to each discrete missile segment. During development, members of the team were able to understand each other's problems and to resolve critical roadblocks to efficient, low cost production. Significant tenets that were established and maintained for good working relationships on the team included

- Engineering designation of critical designs, with a willingness to make exceptions in specifications where required on individual components
- Provision of manufacturing information on producibility limitations to engineering staff, and necessary action to allow manufacturing improvements
- Authority delegated to team members to determine and implement changes
- Open communications for new ideas and concepts.

Hybrid Microelectronics Reduce Weight, Space

In the microelectronics area, 110 thin film hybrid active devices were developed. These replaced approximately 200,000 conventional electronic parts and substantially reduced the weight and envelope of several missile electronic assemblies. Techniques and equipment planned for substrate fabrication and for hybrid device assembly were developed on schedule and within target costs.

As an example of the hybrid development, the three layer thin film substrate shown in the center of Figure 2 is fabricated by first sputtering (coating) an alumina substrate with titanium and palladium. Circuit traces are then electroplated on the coated substrate and the lead frame is bonded. After lead frame bonding, chips are bonded to the substrate, and the part is inspected and tested. The entire

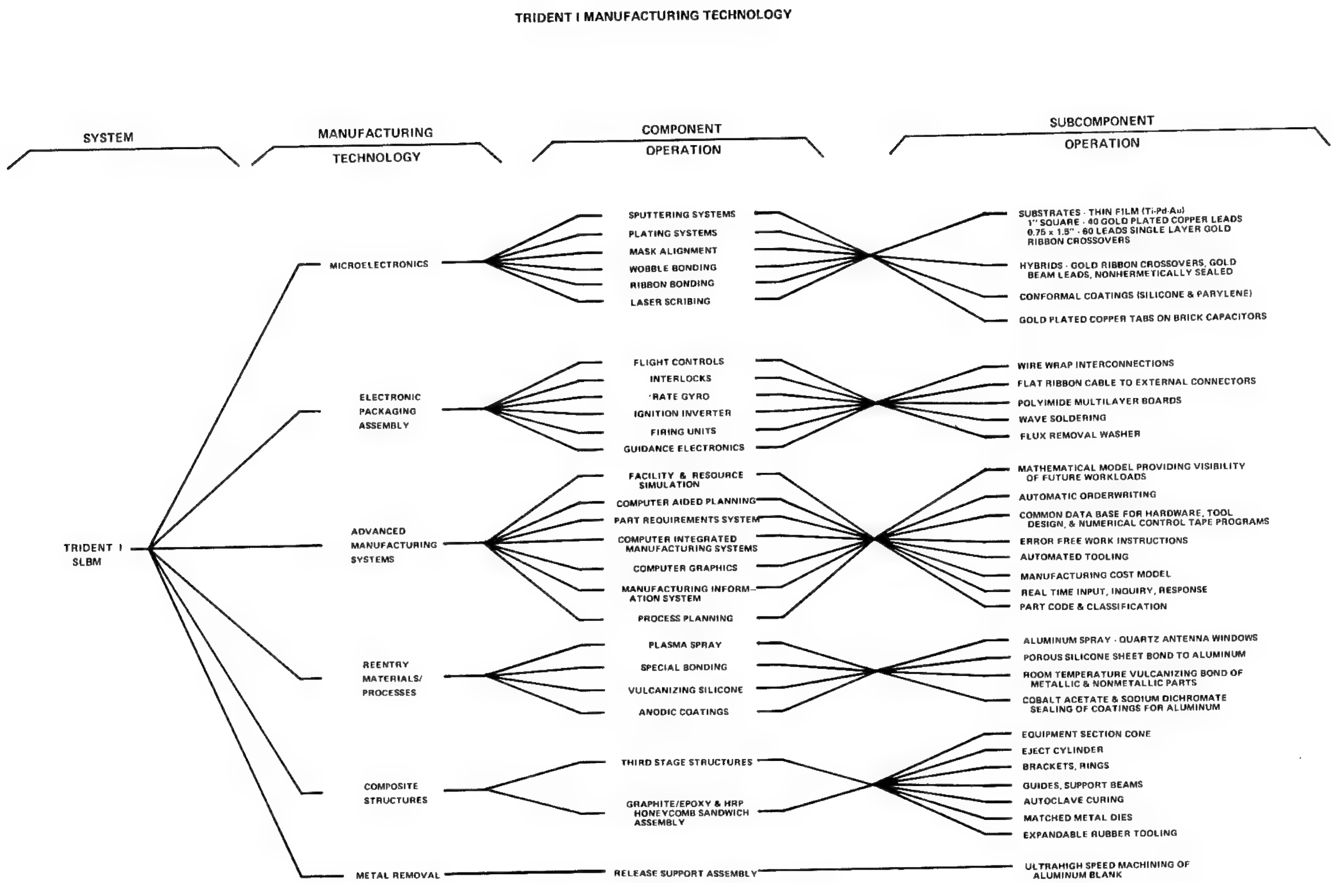


Figure 1

operation required careful development of new manufacturing technology coordinated with part design.

For coating, the substrates are placed in a large vacuum chamber where inert gas plasma is used to transfer metal from two targets to the substrate. First, the substrate is coated with titanium, which wets and bonds to the alumina surface. Then palladium is deposited on the titanium to provide a firm bond and barrier between the titanium underlayer and an outer gold layer which is applied later. The alumina substrates are scribed with an extremely accurate laser beam (0.0001 inch runout for each linear inch), which operates through a computer controlled servomechanism loop. This permits accurate alignment for lead frame bonding and allows the formation of high strength bonds between the lead frame and the substrate electrical circuitry.

Plated lead frames are bonded to the heated substrates by thermocompression bonding and beam lead chips are bonded to the hybrid substrates by the wobble bonding method, a technique that achieves both electrical and mechanical contact in one operation. Reliability is also improved with gold to gold interconnections. A film of Parylene D approximately 0.3 mil thick is deposited on all hybrid surfaces including the underside of the wobble bonded beam lead chips.

Inspection and Testing

A numerically controlled TV microscope allows fast, accurate, and repetitive inspection of small lots of these hybrid assemblies. A separate inspection program is established for each hybrid assembly. To use these, an operator loads the matching control tape and, depressing a foot switch, sequentially inspects each major point on the TV monitor. Localized inspection is then performed with a manually operated control lever.

A high speed digital test system checks parameters of the hybrid assembly active leads and performs all required Trident I hybrid assembly digital testing. This system consists of four multiplexed stations and a high speed line printer. It provides a matrix of 300,000 to 500,000 test circuits, depending on the assembly to be tested. In addition, a digital test system is available to check the analog circuitry parameters.

Thermally Conductive Epoxy Used

Electronic modules for Trident missiles consist of polyimide multilayer boards (MLBs) laminated to heat sinks with acrylic sheet. The sheet is laser burned to match the hole configuration. B-stage thermally conductive epoxy sheeting is used to mount integrated circuit flat packs and hybrids directly to the heat sink side of the module.

For assembly, the components are positioned on the boards and the thermally conductive epoxy is cured in an oven for 45 minutes at 112 C (235 F). After curing, each module is automatically fluxed, preheated, and flow soldered in a single pass through a wave solder machine. This machine was modified with switching circuits to vary the conveyor speed for preheating and wave soldering cycles. Adjustments in speed change the relative temperature to which the module is exposed. Air knives installed in the machine cool the heat sinks as the modules pass beyond the solder wave.

Soldered MLBs are then washed in a Lockheed designed aqueous washer to remove flux residue and ionic contamination. After washing, trimming, and inspection, polyurethane is applied to both sides of the module by making four sequential 90 degree passes to form one coat; two conformal coats are applied to each MLB. Coated modules are tested before kitting for package assembly and failed modules are returned for rework. Kitted modules, interconnects, and the housing (Figure 3), are forwarded to the package assembly area where the modules are installed and interconnected by wire wrap techniques. Each terminal receives a minimum of seven turns of 30 AWG wire. Electronic package inputs and outputs are brought to external connectors with flat ribbon cables and rigid flex circuitry.

A computer program was written to store and retrieve repair history on MLBs. During the assembly of MLBs, before leads are tinned and formed, each component identification is recorded on a traceability data sheet. This identification includes the part number, serial number, lot number, vendor code, and reference designator for each part in the assembly kit. The data is eventually entered into the computer program, which can then display the total module repair history and all assemblies that have used a specific component of a specific lot number.

Knotty Interconnect Problem Solved

By using microelectronics, Lockheed successfully provided the necessary circuitry within critical space and

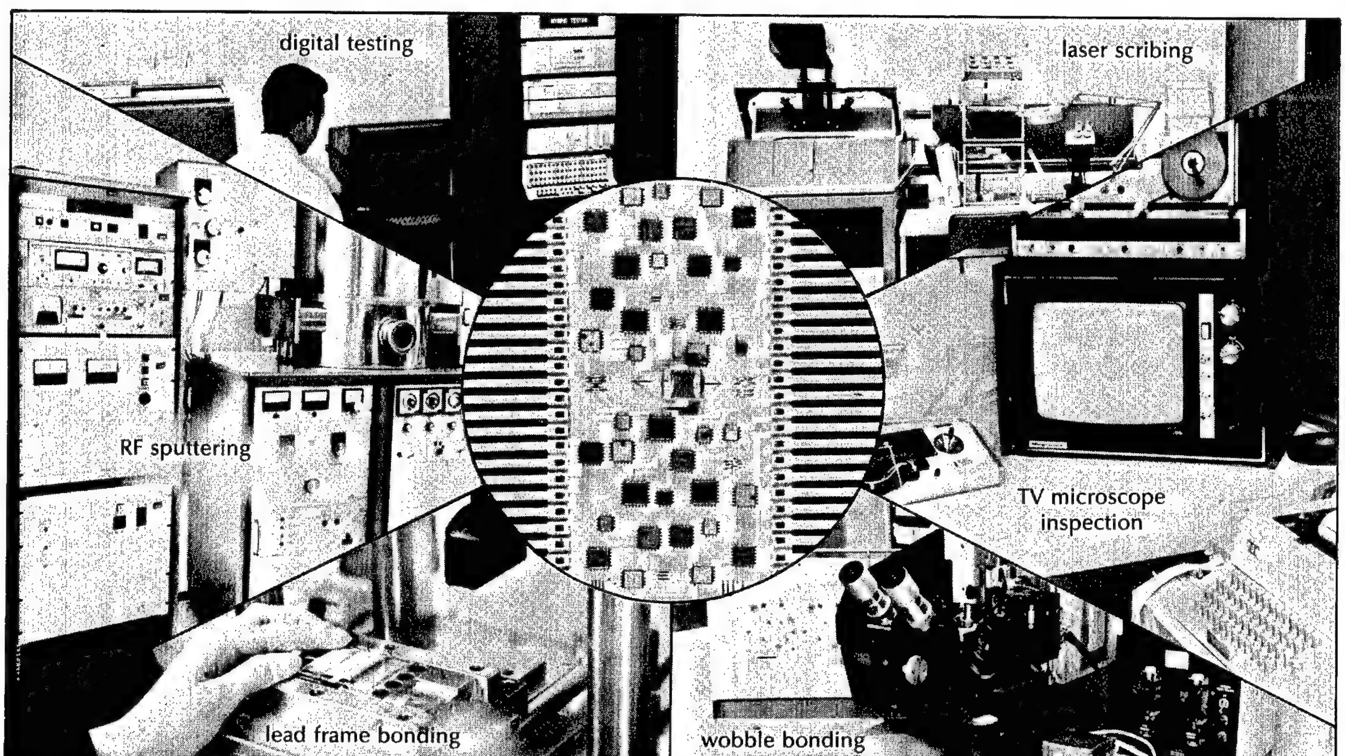


Figure 2

Figure 3

weight parameters. The interconnections (cables and harnesses) between electronic packages still posed a major problem, however. Nevertheless, requirements for low voltage drop, increased shielding, and the number of circuits were successfully met. How this was done is another interesting chapter in the Trident story.

Producibility team members evaluated designs and considered ways of standardizing interconnect variables, including wire, connectors, contacts, shield terminations, and ferrules. They also investigated tooling and assembly methods.

Layouts Produced in One Fifth the Time

As a result, a color coded mylar template was developed for the cable layout using computer graphics. A template contains major dimensions of the engineering drawing and all pertinent notes needed for cable assembly operations. It is used to physically lay out all cable details such as connector mounting brackets, transition blocks, and saddles. Previous methods required a minimum of ten hours to hand draw layout patterns; the mylar layout patterns can be generated in as little as two hours for simple cable assemblies. During cable assembly operations, continuity is automatically checked for end one connections. A Digitrace unit with an audible beep, a digital display, and automatic advance combine to ensure proper termination of end two.

Computer Aid Needs Integration

The use of computers in manufacturing processes is rapidly spreading; they were an important factor in Lockheed's approach to Trident production. An important consideration in bringing the computer into the manufacturing process is that of the total system planning concept. For example, solving an isolated problem by introducing computer aided controls or communications into a matrix of noncomputerized areas almost inevitably leads to

problems in manually operated areas. The total system must be carefully considered when integrating computers into the operation so that the newer, more automated areas will mesh smoothly with the more traditionally operated areas. As one outgrowth of total systems planning, the current trend in computer integrated manufacturing installations is toward the use of smaller computers connected in a hierarchic array rather than a single large computer.

Computer integrated projects for the Trident I missile production program are shown in the SPIDERCHART and are briefly discussed in the following paragraphs.

Facility and Resource Simulation. The manufacturing facility and resource simulator is a computerized mathematical model that integrates manufacturing schedules, lot structures, load factors, machine efficiencies, time standards, and facility capabilities to provide manufacturing engineers and management with data on future workloads in relation to production capability. Output from this real time system includes fabrication spans and associated setbacks, workload profile by load center, workload forecast by part number and cost center, workload versus capability for given time periods, and the average use by load center.

Computer Aided Planning. Originally developed elsewhere in the Lockheed corporate structure, the Computer Aided Planning (CAP) system was modified and applied within the Missile Systems Division (MSD). The online system includes capabilities for estimating hours required for fabricating and assembling missile electronic/electrical packages, test equipment, and machine parts, and automatically resequences all operations after completion. The system also provides for cathode ray tube (CRT) equipment interacting directly with the computer.

The CAP system has significantly improved planning quality, minimized the time required to write error free work instructions, and lowered the total planning cost. This program also provides an important link to the process planning system.

Part Requirements System. The Part Requirements System (PRS) integrates engineering drawing requirements, schedule data, work order application data, manufacturing planning data, model and effectiveness data, end product quantities, and job authority. This single system establishes and maintains product requirements for engineering identified hardware, raw material, purchased parts, kitting data, and associated specifications. Additionally, the PRS improves controls over advanced ordering of materials and allows the manufacturing organization to develop part requirements much earlier in the production cycle.

Computer Graphics. MSD has integrated several data bases into a common data base so that hardware, tool design, and numerical control (NC) tape programs are available at dedicated computer terminals. Significant time is saved in performing tool design operations, performing tool proofing, preparing cable tool layouts, and preparing NC tape programs.

Process Planning. A process planning system is being developed to effectively reduce or eliminate redundant engineering designs, lack of standardized techniques for handling design features, cumbersome methods for retrieving design information, lack of standardized manufacturing processes, and excessive setup costs. The simple interactive system will feature parts classification and coding and the generation of parts families in terms of geometry and form elements.

The manufacturing engineer will be able to interrogate various data files in the computer memory to determine if manufacturing plans for a part family are suitable for a new specific part; to determine if special test or inspection equipment is required to complete the part processing through the factory; or to establish part costs, quality information, inventory level, or tooling requirements. He may either accept the standard operating sequences to make the part or modify the operations by CRT as necessary.

The design engineer will interrogate the files to view similar parts in the system. He may either select an existing design to fulfill his requirements or prepare a new code for the design he desires and enter it into the system. He will also have access to part design costs.

Manufacturing Information System. The current manufacturing information system (MIS) is a real time, fully integrated system with remote input, inquiry, and response capability. It includes eight major programs.

- **Scheduling Program** - provides an automatic schedule assignment and schedule documents.
- **Work Order Assignment** - provides work orders used for identification, collection of costs involved in the manufacturing process, and automatic assignment of work orders.
- **Part Requirements** - provides single source of parts, lists information for use by all organizations.
- **Automatic Orderwriting** - generates requirement information for work documentation after combining all requirements from other requirements programs and establishes computer records that are output as ledgers.
- **Kitting Program** - provides a parts list (manufactured and purchased) for use in kitting of parts and materials required in the manufacturing process.
- **Manufacturing Work Instructions** - provides remote output of shop work authorizing documents and detailed operations to be performed during the manufacturing process.
- **Shop Order Control** - collects labor actuals, budget data, inventory data, and various other reports concerned with performance.
- **Shop Order Location** - reports the location of shop

Figure 4

work authorizing documents, provides short range (24 weeks) and daily shop load reports, and reports on material and parts shortages.

Graphite/Epoxy Used in Structures

Faced with the requirements of extending performance while simultaneously reducing production costs, Missile Systems Division design engineers conducted trade studies early in the conceptual design effort of the Trident I missile. Advanced composites such as boron/epoxy and graphite/epoxy, coupled with advanced design concepts, offered the optimum combination for the desired high strength to weight ratios. After additional testing, the boron/epoxy was eliminated from further consideration because of its high initial cost, low resistance to special environments, and the difficulty and cost of producing complex parts.

Woven graphite cloth was selected as the baseline material because there was no loss of physical properties. This cloth, developed by the Fiberite Corporation in concert with LMSC, was far superior to tape products, as shown by extensive analytical and experimental studies. Thus, a program was initiated to bring graphite/epoxy cloth into the Trident I missile program production phase. Structural test components and full-scale equipment section structures were fabricated to determine the acceptability of the design and reproducibility of the fabrication processes. In all cases, the components met or exceeded the predicted failure loads.

The Trident I missile includes both primary and secondary structures fabricated from graphite/epoxy material (see Figures 4 and 5). The primary structure shown is the equipment section cone which supports the third stage components.

This cone consists of graphite/epoxy facesheets bonded to heat resistant phenolic (HRP) honeycomb core material. To maintain good bond surfaces for the honeycomb core, the forward and aft facesheets are individually laid up and cured with the bond surface next to the bonding tools. The cone is then assembled for autoclave curing. The aft facesheet is positioned on a bonding/assembly tool, adhesive gores are applied, the honeycomb core is aligned over the adhesive gores, additional adhesive gores are applied to the core, and the forward facesheet is aligned over the core. The assembly is bagged and cured at 177 C (350 F) at 0.7MPa (100 psi) for approximately three hours. After curing, the cone assembly is trimmed and machined to accept various secondary structures.

Layup Time Reduced by 55 Percent

The use of graphite/epoxy bidirectional woven cloth on the cone assembly in lieu of unidirectional tape reduced the layup time by 55 percent. The overall assembly quality was improved by better surface condition, elimination of gaps between fibers, and good surface fit at sharp contours. Other advantages include ease of working into tight radii, ease of handling, and the ability to lay up a ply of cloth and remove it for fiber alignment adjustment.

Composite Structures Match Metal Parts

Normally, secondary structures (e.g., brackets, supports, panels, enclosures, cylinders, and other detail parts) are fabricated from aluminum or magnesium alloys. However, these metallic parts are costly to produce because their fabrication involves many time consuming manufacturing operations. Therefore, approximately 60 secondary parts for the Trident missile are fabricated from graphite/epoxy material on expandable rubber tooling, matched metal dies, or a combination of the two. The parts are cured in a hot press, an oven, or an autoclave, depending on the type of tooling used.

Extensive testing showed that the matched die and expanding rubber methods produced components equal in strength to autoclaved components. In many instances the composite parts were of superior quality. Process modifications were made to ensure good pressure in the matched die operations, and the elastomeric (expanding rubber) tools in many cases were heated in a platen press where instantaneous and constant pressure could be applied.

After curing, most composite parts are routed and trimmed with standard tooling. However, a special trim jig is used for sawing, routing, and grinding diameters and chamfers on the aft and forward rings of the equipment section skirt, on the intermediate ring, and on the eject cylinder.

All layup and curing operations are performed in a special environmentally controlled area. The area is also equipped for testing process control specimens used to ensure optimum producibility. Contributing to the producibility of composite structures is the unique equipment and facilities for storing materials, cutting and kitting, layup, curing, and trimming.

Ultrahigh Speed Milling Reduces Costs

Several metallic parts on the Trident I missile require deep pocket milling and thin wall machining with minimum distortion and low residual stresses. Before 1975, NC machining centers in LMSC had limited spindle speeds, machine table feed rates, and rotary table feed rates, which restricted productivity.

To overcome these NC machining limitations, MSD manufacturing initiated an optimum speed machining test program. The program was conducted in two phases: end milling of aluminum alloys and formed cutter milling of cylindrical parts. Tests were conducted to evaluate the effects of cutter design configurations, spindle speed (0 to 100,000 rpm), machine table feed rate (up to 194 ipm), cutter eccentricity and concentricity, chip load per tooth, spindle horsepower, and NC programming techniques.

As cutting speed increased from 4,000 to 20,000 rpm, metal removal efficiency improved 300 percent; pocket milling time was reduced 35 percent; chip size decreased, reducing chip removal problems; chip temperature increased until all cutting energy was contained in the chip, leaving the part at ambient temperature without thermal distortion; and cutter loads decreased, resulting in longer cutter life and lower spindle-bearing loads.

Through a program described elsewhere in this issue, Lockheed has since developed an ultrahigh speed milling system that has provided significant savings to the Trident I missile program. A new machining center was installed to mill the reentry system support structure.

Benefits Also Accrue to Trident II

The planning techniques and manufacturing technologies developed and implemented for Trident I missile production will serve as a stepping stone to Trident II production technology.

Just as it has with Trident I, the producibility team approach will make sure that the advanced techniques and materials in the areas of electronic packaging/assembly, composite structures, computer aided manufacturing systems, and reentry systems will be fully developed. The team approach will also lower costs for all production cycle elements without compromising hardware reliability.

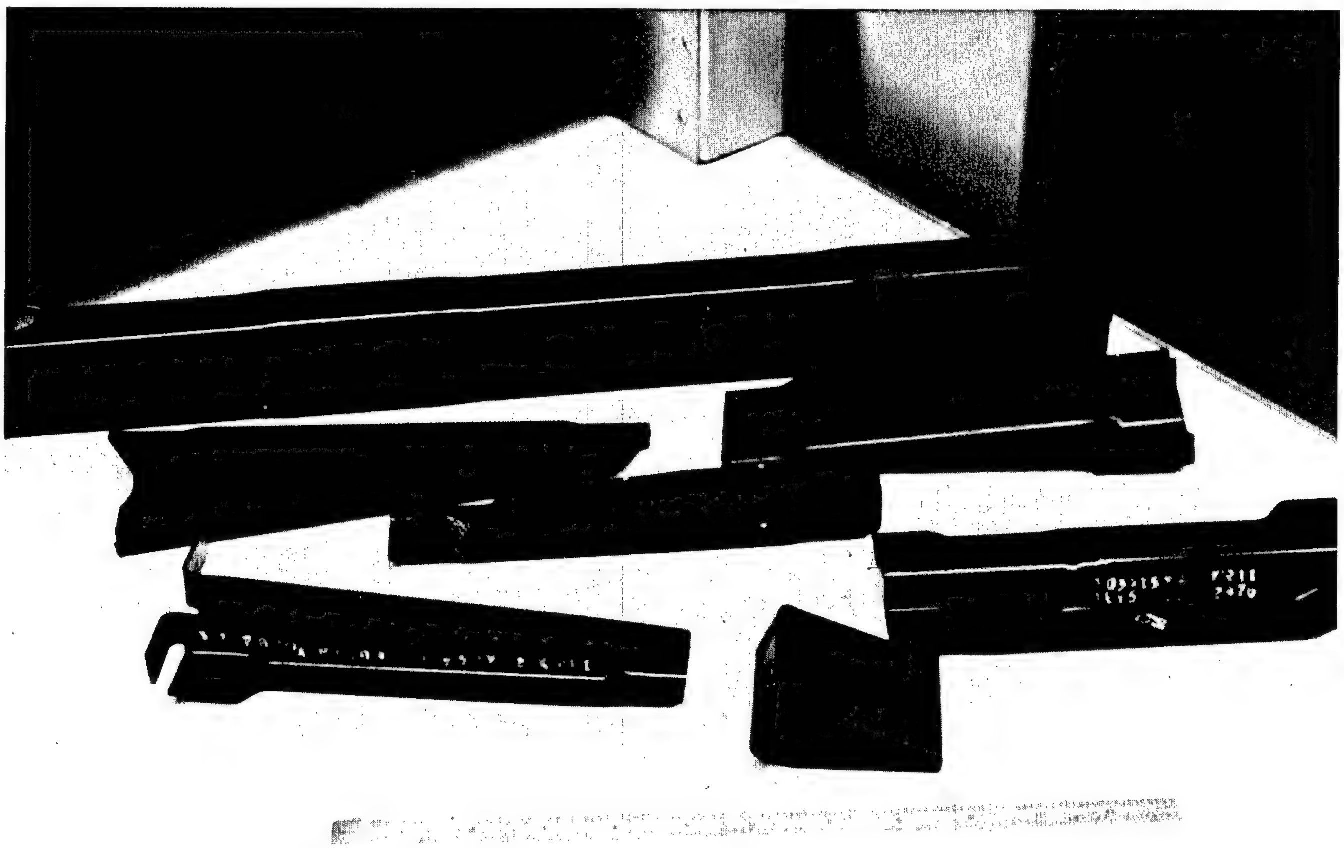
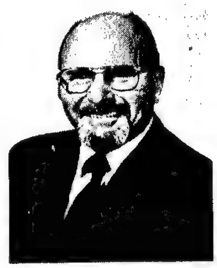


Figure 5

Increased Productivity, Better Parts

Ultrahigh Speed Machining Offers Benefits

Editor's Note: Mr. Albert Reed, who was coauthor of the preceding article on the Reporducibility Team Approach to Trident manufacturing problems, served as editorial consultant on this article on Ultrahigh Speed Machining.



ROBERT I. KING, a consultant in manufacturing at Lockheed's Missile Systems Division, has for the past three years directed the development of facilities, equipment, tooling, and processes for machining at ultrahigh cutting rates. He has had extensive experience in managing manufacturing development and production programs. During his career, he has managed the Titan Missile Underground Launching System, the Apollo Recovery System, and was responsible for the development of new ASW product lines and several electro-optical-mechanical systems. He also was an Assistant Professor of Engineering and Science at Pierce College for five years. He holds a Bachelor of Science degree in Mechanical Engineering from California Institute of Technology and a Master of Science degree from Stanford University and has professional licenses in mechanical and manufacturing engineering. He is a member of the American Society of Mechanical Engineers and the Society of Manufacturing Engineers and has published numerous technical papers.

Extensive testing and research at Lockheed Missiles and Space Company indicate numerous advantages and substantial cost savings for ultrahigh speed machining when compared with conventional processes. Results of Lockheed tests suggest that productivity increases of two to ten times are possible. Furthermore, the ultrahigh speed processes promise improved surface finish and part stability as well as reduced operational costs. Ultrahigh speed machining has already provided significant savings on the Trident I missile program.

With increased productivity, fewer machines will be needed, and, following initial development, cost of the high speed machines should be comparable to that of conventional machines. Finally, ultrahigh speed machining allows the designer to consider many new options. For example, because of reduced cutting loads, the process will have particular advantages with very thin sections.

Lockheed's experiments with ultrahigh speed machining derived from an initial study of the operating cycles of all numerically controlled, multiaxis machining centers within their manufacturing organization. This study generated data that was used to identify and establish priorities for improving steps in the machining process. Two areas were selected for general process improvement throughout the company: (a) part loading, locating, and handling, and (b) chip to chip machining time. Figure 1 shows the average time assessment of a numerically controlled machining center and highlights the cutting time during the study period.

Greater Removal Rates Indicated

The ultrahigh speed machining study was based on the premise that the technology is now available to develop

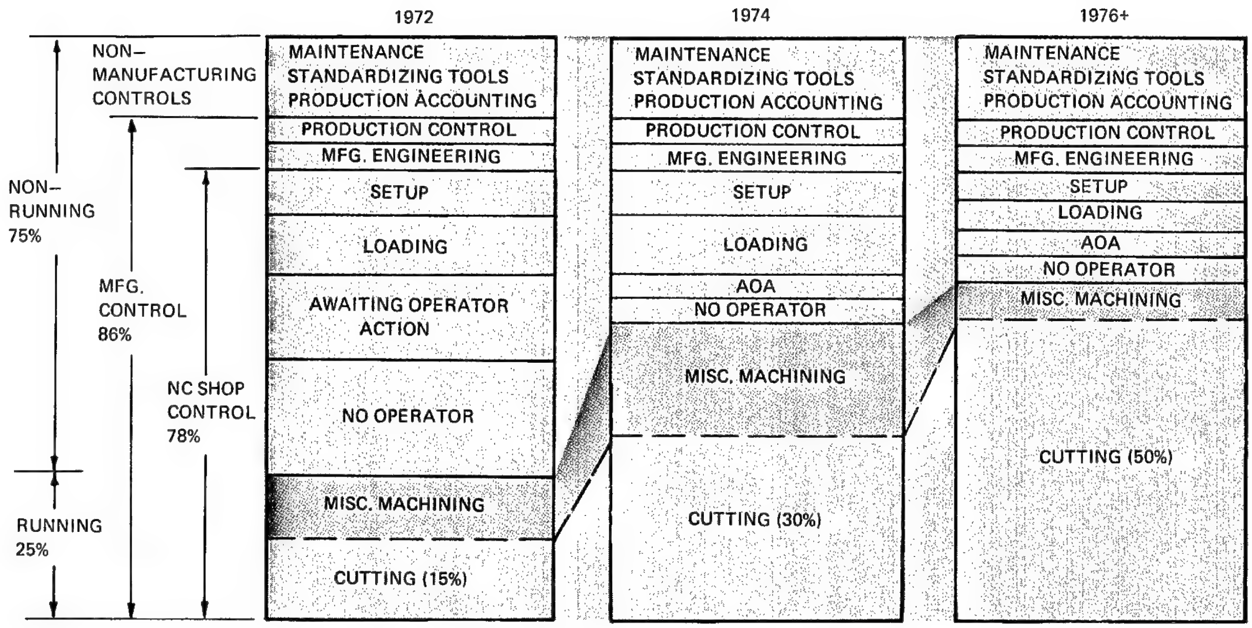


Figure 1

new machines with a significantly greater productivity potential. R. L. Vaughn's research conducted in 1962 at the Lockheed California Company proved that metals will accept chip removal rates several magnitudes greater than those offered in conventional cutting equipment. Preliminary industrial engineering survey results indicated that

- Computer control systems are available that allow machining rates several magnitudes greater than with conventional equipment.
- Newly developed gas and hollow roller bearing designs permit major increases in spindle speeds with no upper speed limit for new spindle bearing installations.
- The use of new aerospace alloys to replace the inherently weak copper components in electric motors permits much greater performance.
- Gas turbine designs offer the additional possibility of completely replacing the electric motor. The torque and speed curves of turbines are inherently better for machine spindle applications (i.e., as the spindle slows down, the torque increases rather than the reverse for electric motors).
- New cutter materials allow much higher cutting rates than are available in conventional machines. Until greater machine cutting rates are available, the maximum performance of present cutting materials cannot be assessed, however.

Careful Test Plan Measures Key Parameters

A test plan was developed that permits spindle speeds and table feeds to be automatically varied up to two magnitudes greater than conventional rates. At the same time, a new cutter family, shown in Figure 2, was designed for compatibility with the higher cutting speeds. The test machines were heavily instrumented to permit quantitative process evaluations.

It was apparent that manually controlled machines could not cope with the higher feeds and speeds required for these machining studies. Additionally, solutions to complex problems were required to optimize the milling cuts. Therefore, two numerically controlled machines were used—a Sundstrand five-axis Model OM-3 mill and a Bullard 36 in. vertical turret lathe. Replacement Bryant spindles were obtained for the mill, permitting a continuously variable speed range up to 100,000 rpm, programmable by the NC system. Table feeds were programmable to 4927.6 mm (194 in.) per minute. Cutter diameters up to 25.4 mm (1 in.) could be used with midrange spindle speeds. At higher speeds, cutter diameter was limited to 6.35 mm (0.25 in.).

The vertical turret lathe was modified to include a table capable of turning 600 rpm and a ram milling head capable of turning 6,000 rpm. This machine was designed to collect cutting data using formed cutters up to a diameter

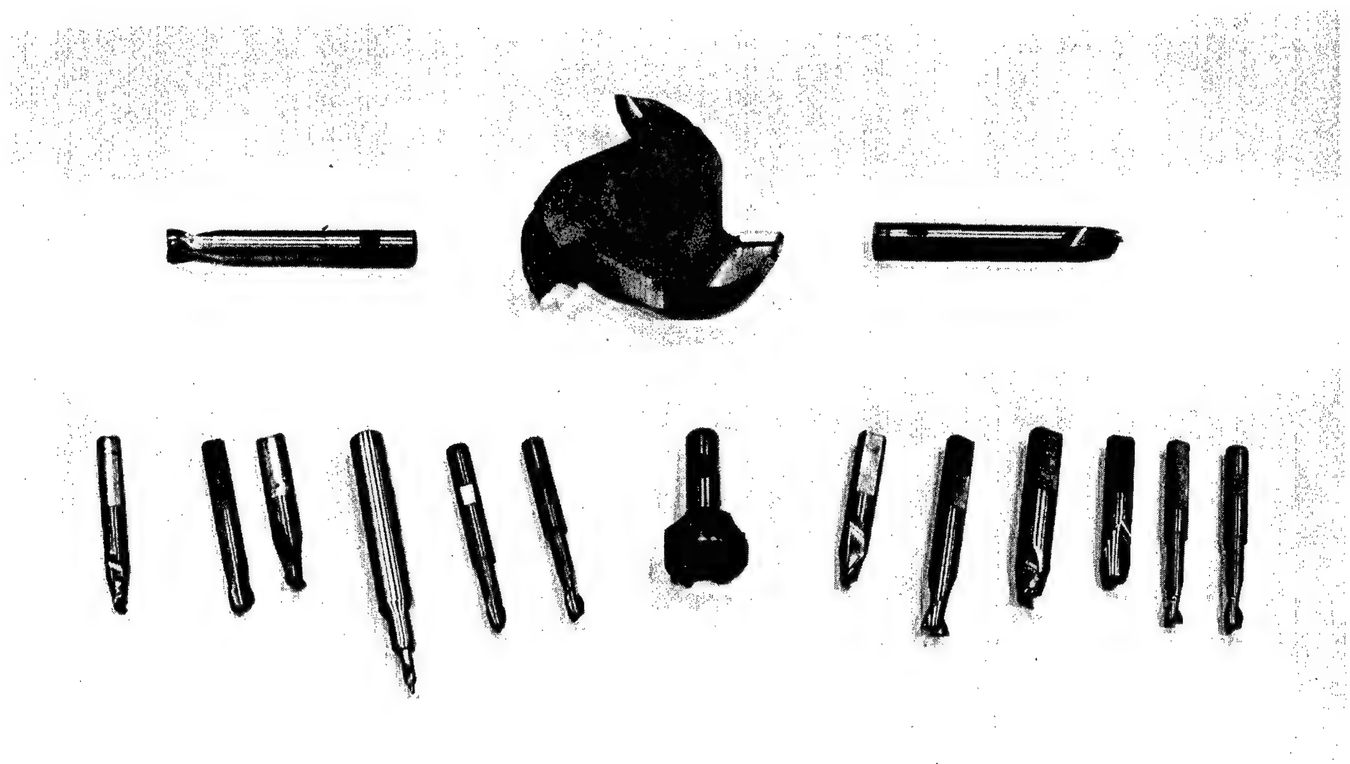


Figure 2

of 203.2 mm (8 in.) at a cutting rate of 60.96 m/sec (12,000 ft/min).

The machining centers were outfitted with dynometers from which static and dynamic cutting force data were obtained. An accelerometer was mounted on the spindle nose to determine resonant effects during spindle operation. Other test data taken included surface finish, temperature, horsepower, cutter wear, equipment configuration, and chip formation. Cutter shape and material were regarded as key considerations for successful material removal.

Dramatic Increases in Productivity

The test program was specifically designed to optimize cutting process productivity, with increases of two to ten times projected from the test results. Moreover, the same technological advances that enhance cutting improvements can also improve other related machining operations. As an example, the run performance of new high speed, four-axis machining centers with spindle speeds of 18,000 rpm show 100 percent improvement over conventional time standards (i.e., one machine replaced two).

Figure 3 shows improvements experienced in cutting efficiencies (cubic inches per minute per horsepower) with increased cutting speeds. Cutting speed increases of 500 percent resulted in a reproducible 300 percent improvement in cutting efficiency regardless of the depth of cut. The data reflected stabilized cutting conditions devoid of

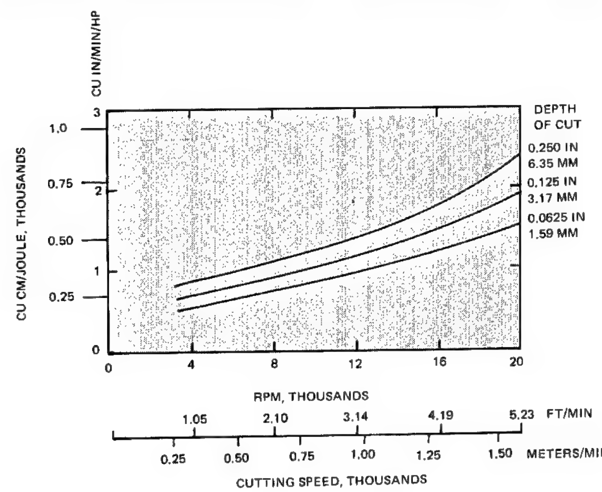


Figure 3

any transient production effects. Machines performing a complex, contouring mode may not necessarily reflect all of these savings. However, as speeds increase, savings increase. The only limiting factors to continued improvements in cutting efficiency appear to be the design of the part being machined and the capability (strength of materials) of the machine. At spindle speeds of 30,000 rpm, a 19.050 mm (0.75 in.) cutter removed metal at a rate of 8 to 10 cubic inches per minute per horsepower.

Low Cutting Loads Vital Element

Low cutter loads are important from the standpoint of cutter wear and part deformation during cutting. The cutter wear rate has an important influence on in-process part dimensional changes, as well as cutter resharpening and replacement costs. Excessive loads can cause undesirable cutter deflections and breakage. Part deformation caused by cutter loads can exceed the elastic limit of the material, cause uneven permanent distortion, and limit the thinness of parts that can be practically machined. With conventional machining, maximum productivity requires machining at the maximum practical cutter load. Thus load becomes a very real limiting factor in the capabilities of the process. Ultrahigh speed machining overcomes these limitations.

The reduced cutting loads at higher cutting speeds offer significant advantages for both turned and milled parts. For example, symmetrical thin shell parts, normally made by either single or ganged point turning, incur extremely high forces between the part and the tool, causing distortion of the part and serious dimensional control problems during fabrication. The use of ultrahigh speed milling for such parts reduces localized loads, permitting easier dimensional control, thinner shells, and reduced fabrication time. Additionally, a high speed turning operation produces small, easily removed chips, eliminating the disposal problem of long, curling chips.

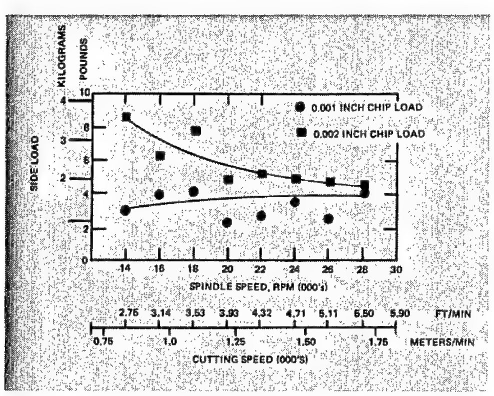
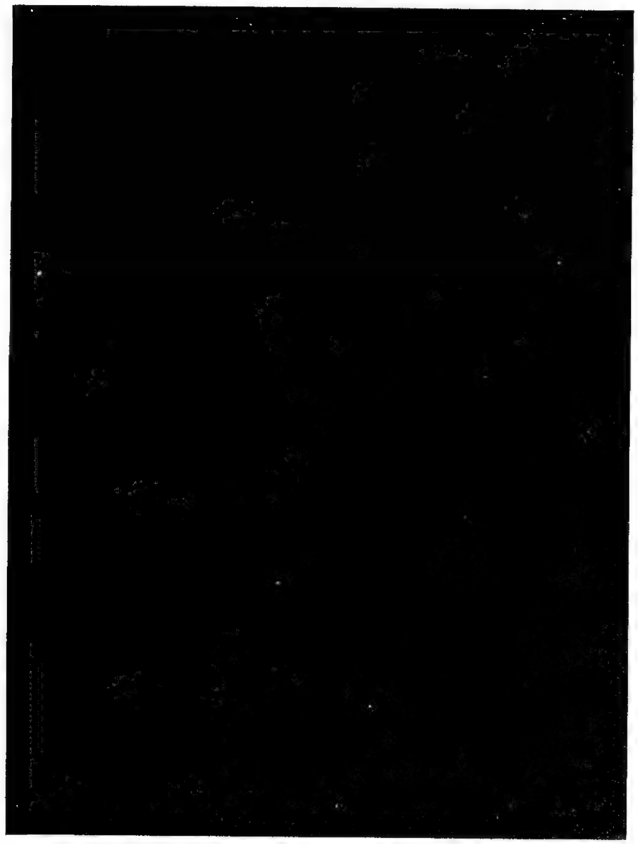


Figure 5



As shown in Figures 4 and 5, the cutting rate has a significant influence on cutting forces. For the same chip load (chip thickness) and depth of cut for a given milling cutter, the side load was reduced by 70 percent when the spindle speed was increased from 4,000 to 20,000 rpm during roughing operations. In all cases, cutter forces were greatly decreased by increasing cutting speeds. Thinner sections than previously thought practical were milled, with straighter, deeper cuts and closer tolerances.

Vector Control Critical

Another part design influence is the vector control of cutting forces during milling operations. It is possible to regulate the magnitude and direction of cutter forces on the part by a careful selection of cutter speed, feed, and depth of cut. Figure 6 summarizes tests conducted to demonstrate force control with milling cutters.

As an example, consider the aluminum alloy part shown in Figure 7. The pockets in this part could be readily cut with interconnecting webs (thickness under 2.54 mm (0.1 in.), depth 69.85 mm (2.75 in.) and surface finish 25 to 60 rms) without any distortion in a high speed production mode. Furthermore, they could be cut 50 percent faster than heavier sections cut at normal speeds. Proper machine

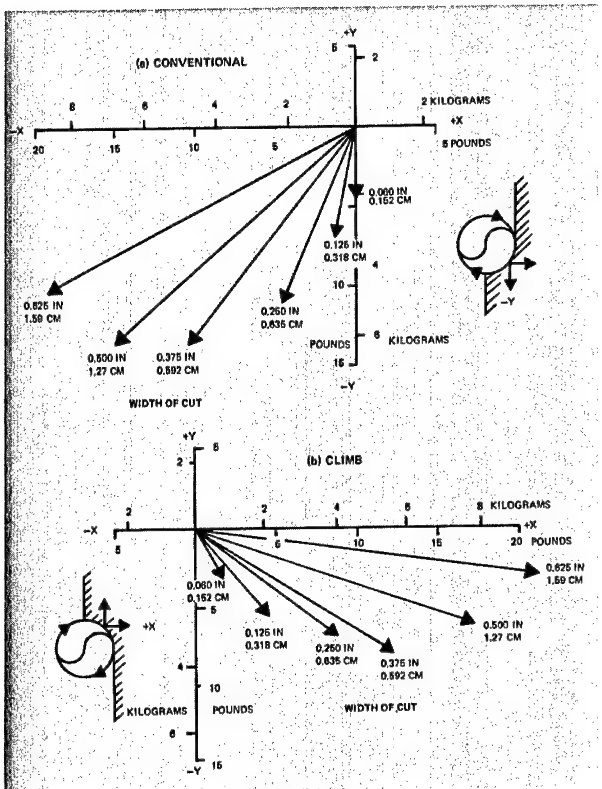


Figure 6

control permits complex part configurations—previously considered impractical—to be machined.

Optimized use of cutter forces, however, presupposes proper understanding and use of other technical considerations, such as

- Transient machine and cutter effects during any change in the cutting program
- Original material specification
- Process effects on the material
- The manufacturing area environment.

The higher cutter speeds suggest computer controlled machines in lieu of manually controlled machines. Likewise, the manufacturing planner and machine programmer require more extensive technical backgrounds.

Part Stability Prime Factor

Aside from the obvious advantages of product improvements and lowered costs with increased cutting speeds, many technical benefits result from improved part stability during machining. This stability includes lower, more uniform temperature, lower machining loads, and lower induced residual part stresses. The thermal effects of ultrahigh speed are quite pronounced—the higher the cutting speed, the cooler the part and the hotter the chips.

For cutting speeds greater than 5,000 surface feet per minute the temperature rise of the part is barely detectable, but the chips become hot enough to cause operational problems. If coolant is used during machining, control of the chips is easy. If no coolant is used (dry cutting), spontaneous combustion of extremely small, hot chips can become a serious problem. Care must also be taken to make sure that the cutter design takes full advantage of the speed range used, or the desired technical advantage will be negated.

The part shown in Figure 7 typifies the improvement in part stability that can be expected through ultrahigh speed end milling. The webs would normally be at least 4.699 mm (0.19 in.) and the corner radii would be no less than 12.7 mm (0.5 in.). The webs shown are one third of this value and the corner radii can be made 6.35 mm (0.5 in.). Both dimensions are obtained without unusual operations and at less cost. Note that the cutting loads approach a constant value at the high speeds, regardless of the chip load.

An increase in cutting speed also significantly reduces hardening and imperfections normally attributed to the cutting operation, as shown by metallurgical inspection. In addition, parts that are properly stress relieved before machining will remain that way, provided that the cutting speed is high enough (e.g., a safe cutting speed in aluminum is 5,000 surface feet per minute). Ultrahigh speed milling also promises to eliminate many grinding and honing operations.

Surface Finish Improved

Surface finish is one of the most difficult machining characteristics to predict when qualifying either a new machine or a process for production. Improvement is extremely expensive, and erratic performance is difficult to find and to correct. Resonant vibration conditions in the part, tool, spindle, and machine all have detrimental effects on part surface finish. As milling cutter speeds increase, more high frequency resonances are encountered that result in cutter chatter, which in turn produces rough finishes and causes tool breakage. A penetrating analysis by Colwell and Quackenbush of the University of Michigan recognized this problem. They suggested superimposing

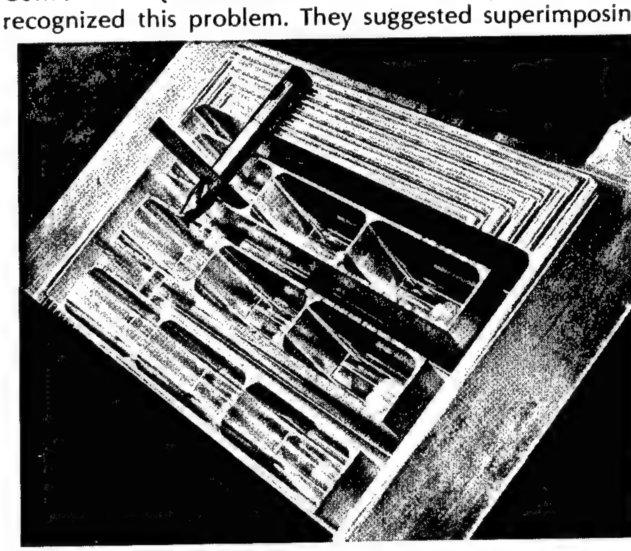


Figure 7

higher frequency vibrations to inhibit the detrimental resonances.

The chatter problem is a constant annoyance during a test program and defeats many attempts to correlate surface finish with cutting speed and other parameters. The techniques suggested by Colwell and Quackenbush have not yet been tried in the Lockheed investigations but will be in future tests. However, there is sufficient data to suggest that surface finish is significantly improved with increased cutting speed once the problem of inherent resonance is overcome. This is indicated in Figure 8, which compares surface finish with spindle and cutting speeds.

Surface hardening effects also are less pronounced at the higher cutting speeds. This can be predicted from the hypothesis that the chip formation mechanism changes from plastic to brittle fracturing, leaving more of the energy of cutting in the chip and less in the part. Skin cuts have been made with negligible tooth chip loads, low machine feeds, and cutter speeds well over 20,000 rpm, resulting in a mirror finish on a soft substrate. The part remained at ambient temperature while the chips were extremely hot. No surface hardening or burnishing was observed.

Benefits Extend Beyond Machining

While the major economic advantage of ultrahigh speed milling is in the significant reduction in time required for metal removal, other elements of the production process also benefit.

The inherent capability of the ultrahigh speed milling process to dissipate heat in the chip rather than in the part provides savings in subsequent operations. For example:

- Stress relieving would not be necessary following ultra high speed milling.
- When aluminum sheet stock is drilled at high speeds, subsequent deburring operations may be reduced by as much as 80 percent. The entrance side of the hole displays a barely discernible eruption burr, while the exit side is clean.
- Part configurations using castings or forgings often require unique holding fixtures. Ultrahigh speed milling will eliminate the need for these costly fixtures.

Ultrahigh speed milling should reduce not only operating costs, but overhead costs as well. Fewer machines will be required to produce the same number of parts with a projected productivity increase ratio of from 2:1 to 10:1 over conventional NC milling. Conventional and high speed NC machine costs should be comparable, once the initial development of high speed equipment is accomplished. Fewer machines with no increase in acquisition price translates into a lower capital investment requirement for both equipment and space.

Picture Not Yet Complete

Although the Lockheed study indicates considerable economic advantage for ultrahigh speed milling, there are areas such as cutter life and cost that still must be examined in depth before all the problems will be solved.

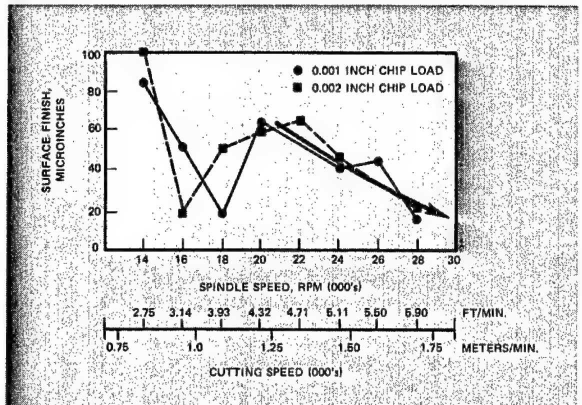


Figure 8

Available data indicates that ultrahigh speed cutter life compares favorably with conventional cutter life. It must be stressed, however, that these cutters have not been exposed to the rigors of daily production use. Cutter materials and configurations are not totally specified; it is probable that carbide will be used more extensively. The basic machines and control unit are known quantities, but machine uptime and maintenance costs of ultrahigh speed spindles, driven in a milling mode with 25 hp, are important considerations for milling machine designers.

Chip removal from the machining areas will require more attention and planning. Because the chip production rate is much greater with ultrahigh speed milling, it is likely that more elaborate automatic chip removal systems will be required, although the basic chip is smaller and easier to handle.

Benefits Available Now

Despite these gaps, the investigation of ultrahigh speed milling techniques has demonstrated that significant savings can be realized during production periods. Current factory equipment and tooling can be modified to improve cutting speeds, while new machines developed for specific requirements will provide maximum benefits. Many of the parameters currently used in technical economic tradeoff analyses to support product design decisions should be reevaluated in light of new ultrahigh speed milling production methods.

Reduced cutting loads, improved part stability, and improved product surface conditions offer the designer many options in developing configurations that heretofore had been considered impossible. Of particular interest are those parts where thin sections are important.

The only limitation to additional progress is the strength of machine tool materials. Therefore, it is reasonable to assume that process improvements of one magnitude are possible with present day technology and should be available within ten years.

Longer Lived Coolants

A New Cutting Fluid Technology

Higher productivity...elimination of waste disposal problems...conservation of raw materials...less downtime...fewer machine maintenance problems...longer tool life. Worthwhile, cost saving goals for any machining operation—goals that can be reached by using long lived, water miscible cutting and grinding fluids and applying proper control technology.

Proper control means a supply of pure water, close watch on coolant concentration, careful cleaning of the machine sump, and removal of tramp oils from the fluids. The technology and know-how to achieve such control is available and is being applied in many machining operations. The resultant savings are dramatic.

New Problems Arise

The need for longer lived coolants goes beyond merely accruing the advantages and cost reductions listed above, however. Stringent pollution regulations and rising costs of petrochemicals demand longer lived products. One just can't dispose of coolants every week or so any longer. Now we have to run fluids for a year or more—which introduces new problems requiring new and improved technology.

In the first place, as the water used to mix the coolant fluids evaporates from the sump it leaves dissolved minerals behind. This was not a significant problem when coolants were run for only a short time. Now, however, the accumulation of dissolved minerals can influence machine performance and coolant particle size, contribute to corrosion, and cause microbial growth—all leading to shorter tool life.

As General Manager of Master Chemical Corporation's Systems Equipment Operations, WILLIAM A. SLUHAN directs the design and manufacture of his company's innovative line of light to heavy duty machine sump cleaners. He also coordinates the integration of other equipment components (e.g., proportioning pump, water deionizer, centrifuge) into the antipollution Closed Loop™ System for superior metalworking efficiency. Upon graduation from Ohio Wesleyan University in 1964 with majors in Chemistry and Business Administration, Mr. Sluhan joined the Master Chemical Corporation as a salesman. In 1966 he joined the U.S. Army and served with the Third Armored Division in Germany until 1968. He then returned to Master Chemical Corporation as Assistant to the Sales Manager and Director of Product Service and Evaluation, responsible for the field testing and evaluation of Research and Development Products. In 1973, he was promoted to Vice President, Operations, and assumed his present responsibilities in 1976. Mr. Sluhan is a member of SME and serves on the Metalworking Fluids Subcommittee of SME'S Material Removal Division.

Another problem involves control of coolant concentration levels. While always important to a coolant's cutting or grinding performance, concentration control was irrelevant to the life of water miscible fluids that were only expected to run a week or two anyway. But with long lived fluids, careful control of fluid concentration is an absolute necessity.

Cleanliness Mandatory

Machine cleaning practice influences both fluid performance and longevity and presents a third problem. Poor cleaning leaves a swarf or silt in the coolant sump. The coolant picks up this foreign matter and circulates it back over the work. This can scratch the workpiece and can also reduce tool life. Additionally, microbes, which reduce fluid life, find the swarf a perfect breeding ground.

A final problem: as long as coolants were discarded frequently, tramp oil contamination was not a major concern; now it has become one. High levels of tramp oil reduce the cooling ability of water miscible fluids; tend to form sticky, gummy residues on a machine's moving parts; reduce the wetting and penetration properties of surface active coolants; and tend to foster the growth of undesirable bacteria.

Those are the major problems. Let's consider the technology and know-how we said was available to meet them.

Pure Water Licks Mineral Buildup

Mixing coolants with pure water offers an easy solution to the problem of mineral buildup. The pure water can be obtained by distillation, reverse osmosis, or deionization.

Many plants have a ready supply of distilled water from boiler condensate. Using this to mix coolants involves little or no additional cost. Likewise, some plants have electroplating facilities that include deionizers. Unless the plating operations completely tax the deionizer capacity, pure water is again supplied at no additional cost. In most cases, reverse osmosis is a more costly and less convenient process and is also less satisfactory, so normally is not used.

In the absence of ready made facilities, deionization utilizing negatively and positively charged ion exchange resins is probably the cheapest way to obtain the relatively large amounts of high purity water needed. High capacity, fully automatic deionizers that take advantage of recent advances in resin composition and solid state circuitry are now available. These machines require very little floor space and virtually no attention or maintenance. Figure 1 shows a typical unit. Such units feature fully automatic regeneration processes which are triggered by declining water quality, by a timer, or by metered water. Recirculation pumps keep water flowing through the resin beds at all times. This makes sure that high purity water is always available even though the deionizer is called upon only intermittently.

Least Expensive Path

High purity water from automatic deionizers of this type costs only 0.25 to 0.75 cent per gallon, including chemical costs and amortization over a five year period. This translates to just pennies per machine per day. The water will pay for itself many times over in reduced coolant disposal costs alone. Furthermore, the use of pure water eliminates the major source of mineral contamination.

The continual use of pure water also helps to maintain small coolant particle size and a uniform chemical composition. This improves the uniformity of metal removal over extended periods.

Finally, the use of pure water eliminates dissolved mineral reactions, minimizes carryoff, lowers fluid concentration, and allows less frequent disposal—all of which means drastic reduction in fluid concentrate use. A reduction of 30 to 40 percent compared with untreated water is normal and can be as high as 70 or 80 percent. The advantages of using pure water, then, are (1) optimum fluid performance, (2) low fluid concentrate usage, and (3) few disposal and pollution problems.

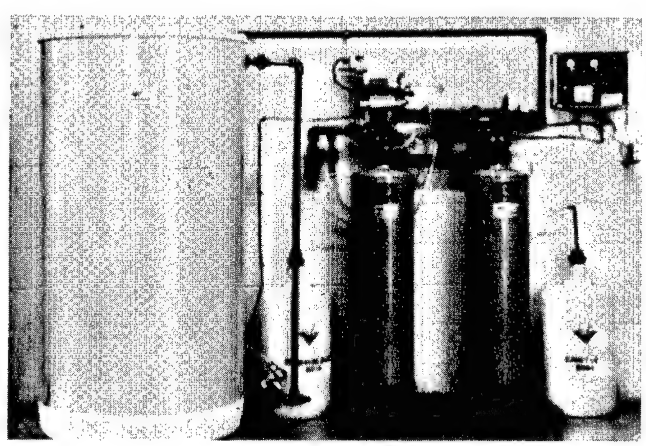


Figure 1

Careful Control Reduces Usage

The second problem involves control of the coolant concentration. Historically, such control has been sadly ignored by the metalworking industry. Haphazard operator controlled methods have been the norm. The need for proper control, however, is highly important to tool life, corrosion control, and resistance to microbial growth. The use of long lived coolants has emphasized this need.

Recently developed variable ratio, positive displacement proportioning pumps (Figure 2) provide effective, automatic concentration control. These pumps are unaffected by changes in water pressure, flow rate, or concentrate viscosity because both the diluting water (which also drives the unit) and the fluid concentrate are physically metered.

These pumps generally provide not only initial coolant charge and makeup solutions for machines with individual sumps but also makeup additions for central systems. Experience indicates that savings of about 15 percent in coolant usage can be expected in comparison with any manual mixing method. Additional savings arise from reduced corrosion and reduced coolant rancidity, although these savings are harder to pin down.

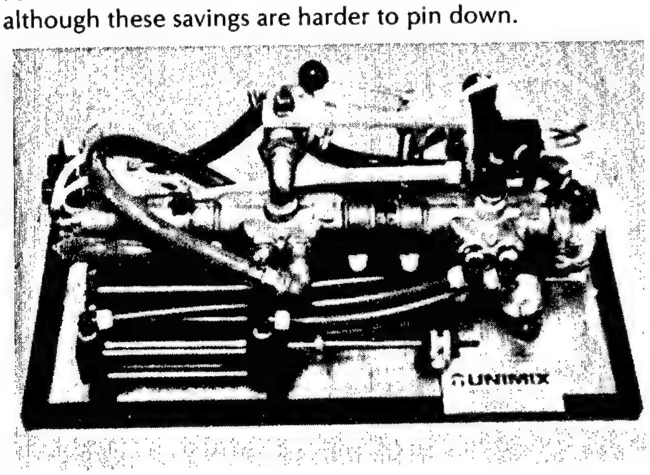


Figure 2

Cleaning Technology Effective

A third major problem to be considered is cleanliness of the machine sump. Until recently, buckets, scoops, rakes, and sometimes a liquid vacuum that could suck out old coolant (but not solids) were used for this undesirable chore. It was a dirty, messy job—one often either neglected or done poorly. Now, machine cleaning equipment of the type shown in Figure 3 makes the job quicker, cleaner, and easier. Several companies make such cleaners; they may differ in detail, but all have Roots type blowers driven by motors of a minimum of five horsepower. Such equipment sucks used coolants from machines at a rate of approximately fifty to one hundred gallons per minute and picks up any solids that fit through the two inch diameter hose. With equipment like this, even hard to reach sumps are cleaned quickly and thoroughly.

Such cleaners also have chip or swarf baskets that filter the coolant as it is sucked from the sump. With the blower reversed, the machine then returns the filtered coolant to the sump for further use, assuming it is not rancid or contaminated with tramp oil.

Coolant that is contaminated but not rancid is pumped into a holding tank. There the fine particles settle out and most of the tramp oil floats to the top where it is skimmed off. The reclaimed coolant then can be reused.

The power of these machines helps ensure thorough cleaning, thus increasing coolant sump life. Furthermore, cleaning is much quicker, reducing downtime and increasing productivity. Downtime may be reduced as much as 80 percent, offering significant savings.

Self Cleaning Centrifuge Controls Tramp Oil

The final problem to be met in utilizing long lived water miscible fluids is that of tramp oil control. This should be tackled early. The proper selection of lubricating oils, hydraulic oils, and greases offers the best insurance of continued uninterrupted machine tool performance.

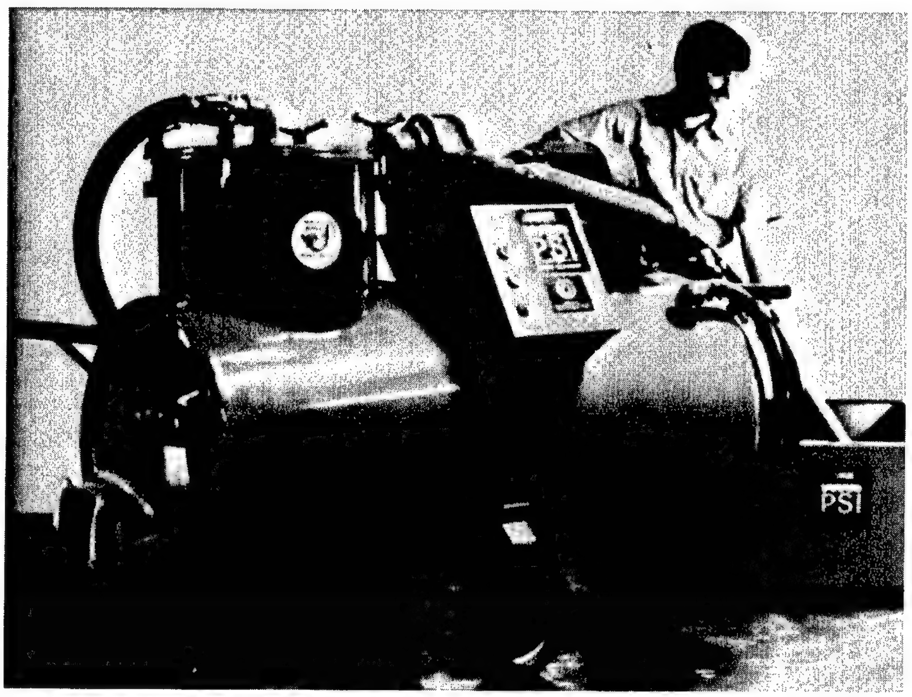


Figure 3

Improper lubricants will contaminate the coolant and may affect any of the following:

- Rust and corrosion
- Reduced specific heat and rate of heat conductivity of the coolant, thereby reducing tool life
- Reduced wetting ability of the coolant
- Increased bacterial growth
- Reduced filterability
- More difficult monitoring of coolant concentration
- Sticky residue
- Dirty operation
- Decreased coolant longevity
- Skin rashes.

When selecting oils and lubricants, consider how well they perform their basic function and how well they resist water miscible fluids or emulsification in the fluid. The use of a coolant that resists emulsification helps to eliminate each of the above problems and makes it much easier to maintain oil levels at the criterion of less than 0.5 percent.

Centrifuging provides the most effective way to remove tramp oil that does occur. The centrifuge is a high speed, disk bowl separator that generates forces of about 8,500 g's to separate the tramp oil (light phase) from the coolant (heavy phase). The automatic, self cleaning centrifuge (illustrated in Figure 4) requires practically no maintenance and is easily the most economical type

available. It not only separates free tramp oil from the coolant but also breaks up and separates loosely emulsified tramp oil. Although these self cleaning centrifuges cost about 50 percent more than the manually cleaned types, the savings in maintenance expense quickly makes up the difference in initial cost.

A New Standard Evolves

All of this tells us that we need stable, long lived coolants mixed with pure water at proper concentrations and kept free of tramp oil. When put into machines that are kept clean, these coolants will go a long way toward eliminating coolant disposal problems.

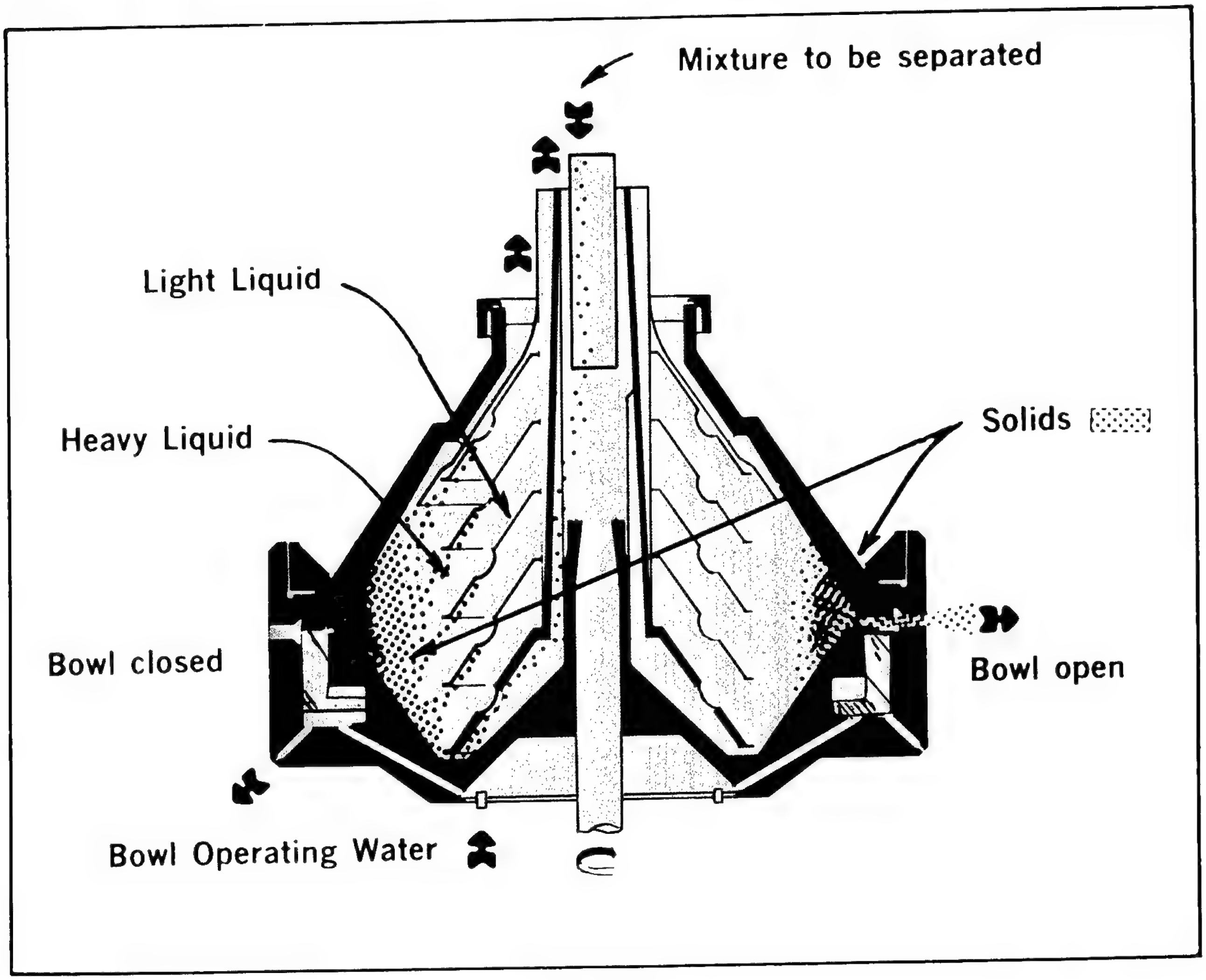


Figure 4

Microdrill Developed for Tiny, Deep Holes

Adaptive Control Reduces Drill Breakage

Adopting a do it yourself attitude, General Electric has developed a machine in cooperation with Westhoff Machine Company that has unique capabilities for drilling small holes in expensive materials. Adjustable for both maximum torque and end pressure, the microdrilling machine minimizes drill breakage as well as drill wander in holes with a high ratio of depth to diameter.

When General Electric encountered a very costly breakage problem in drilling deep sensor holes in carbon to carbon ablation materials, they decided a more reliable drilling method was required. In addition to the cost of broken drills and downtime while replacing them, drill breakage resulted in considerable scrap losses for parts from which the broken drills could not be removed. When they couldn't find equipment needed to meet the requirements on the market, they decided to adapt what they already had.

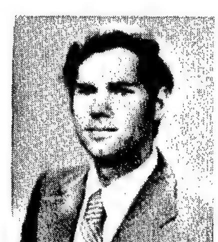
The troublesome operation involved drilling 0.015 inch diameter holes up to 4 inches deep for instrumentation implants at G.E.'s Reentry and Environmental Systems Division. The Westhoff 300M drilling machine used for this operation is a horizontal drill with an infeed quill suspended on an air bearing (Figure 1). Using the 300M drill, infeed rate and pressure are operator dependent with a one to one ratio between operator hand pressure and drill tip pressure. More reliable control of pressure was needed to prevent drill breakage.

Drilling Requirements Identified

Looking more closely at specific needs, G.E. listed desirable features or actual requirements for a drilling machine:

- Horizontal drilling capability for chip removal in deep holes
- Minimum spindle run out—less than 0.0005 in. to accommodate drills as small as 0.005 in. diameter
- Precise workpiece locating capability
- Hollow spindle in order to short chuck long microdrills
- Automatic infeed and retract control
- Torque and end pressure feedback control
- Timed pecking control for chip removal.

RONALD A PRIEST graduated from Widener College with a degree in Management in 1970 and completed General Electric's Manufacturing Management Training Program in 1972. In 1973, he worked with the G.E. Wiring Devices Business Department in Providence, R.I. He joined G.E.'s Reentry and Environmental Systems Division in 1974 as a Producibility Specialist, developing a Microdrilling Laboratory to meet MK-12 reentry sensor implant requirements. In 1976 he was promoted to Advanced Manufacturing Engineer, working with state of the art manufacturing processes to meet MK-12A R&D and production requirements.



Searching for an available microdrilling machine to meet these requirements, G.E. found several automatic infeed drills. However, none of these offered the necessary automatic retract on torque and end pressure, and none could handle drills in the 0.005 to 0.020 in. diameter range. Looking again at what they already had, G.E. found that the Westhoff 300M machine satisfied four of the seven requirements. Since it appeared it could be adapted to meet the other requirements, they decided to create an automatic version of the 300M Manual Infeed Machine with the help of Westhoff.

Westhoff agreed to design and build the mechanical portion of an automated drill while G.E. designed and built the necessary electronics, including power supplies and controls, to create the desired microdrilling machine.

Compromise Machine Developed

The result of this effort is the 300A, an automatic drill with adaptive control. The 300A offers unique capabilities in drilling small holes in expensive materials. The problem

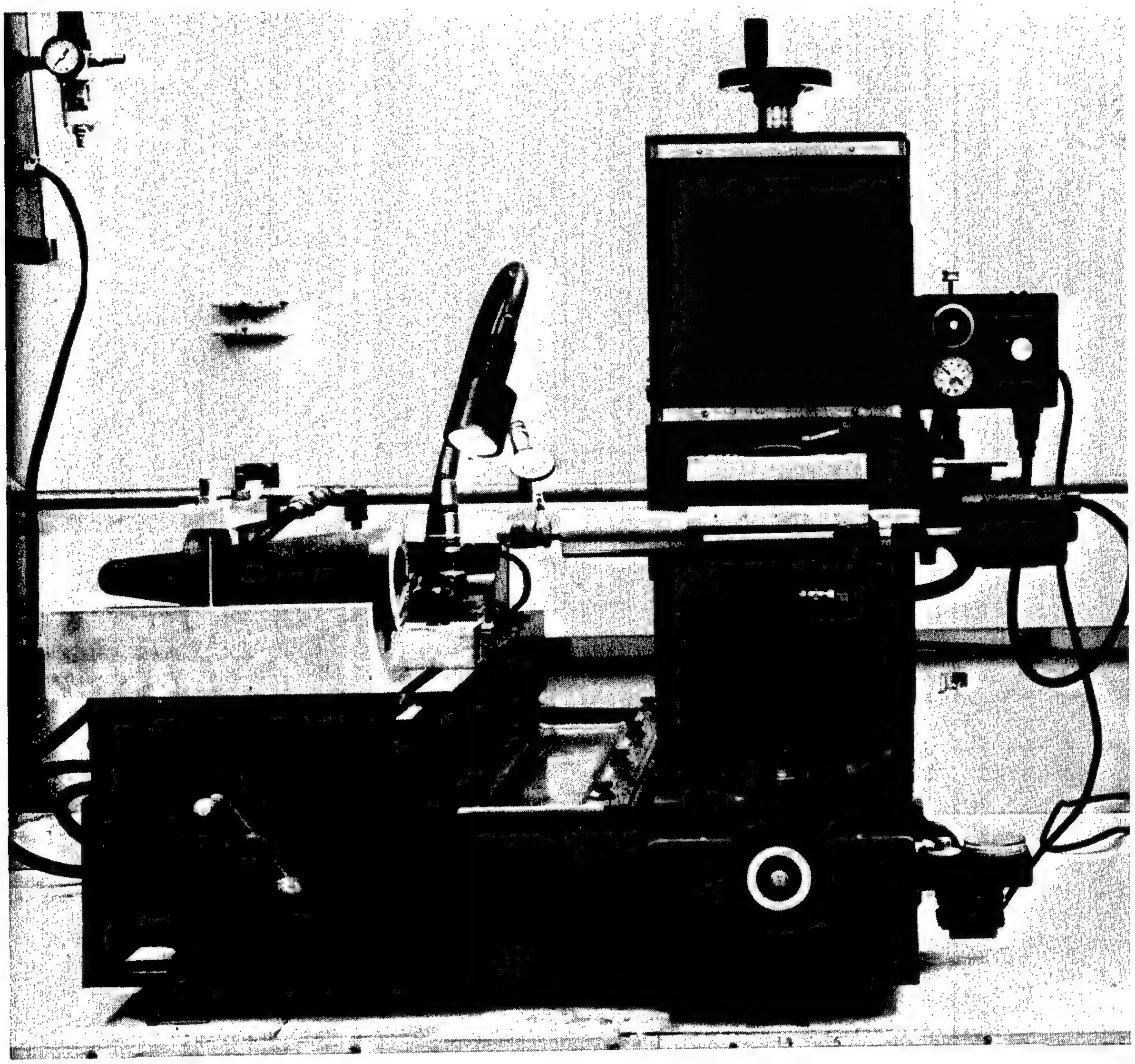


Figure 1

of drill breakage is minimized by adjusting the machine for maximum torque and end pressure. The proper adjustments are established through experience and from results of destructive tests in which drills are stressed to their yield points. Once the machine is set up to drill a hole of given diameter in a particular material, the chance of drill breakage is greatly reduced. Operator fatigue and associated reduction in sensitivity are no longer a problem.

Another benefit of the machine is its ability to drill holes at a very slow, controlled infeed rate. The machine has been designed to drill as slow a rate as 0.020 in. per minute; this controlled rate is very effective in minimizing drill wander in holes with a large depth to diameter ratio.

An extraordinary value of the adaptive control feature is its ability to monitor drill wear. As the drill begins to dull, the pecking or retract rate increases due to the increased torque and/or end pressure required to drill through the material. The operator can time the pecking rate and determine when a drill is dulled to the point that it needs resharpening or replacement. The drill has been adapted to a multichannel chart recorder which simultaneously records the following parameters on graph paper:

- Spindle speed
- Spindle current
- Infeed rate
- Infeed pressure
- Drill displacement (depth).

By combining the adaptive control feedback capability of the drill with the multichannel chart recorder output, drill optimization studies are easily accomplished. These studies can be set up to optimize drill point configurations and usage of drill materials and to determine optimum feed and speed curves. Figure 2 is an example of a typical chart.

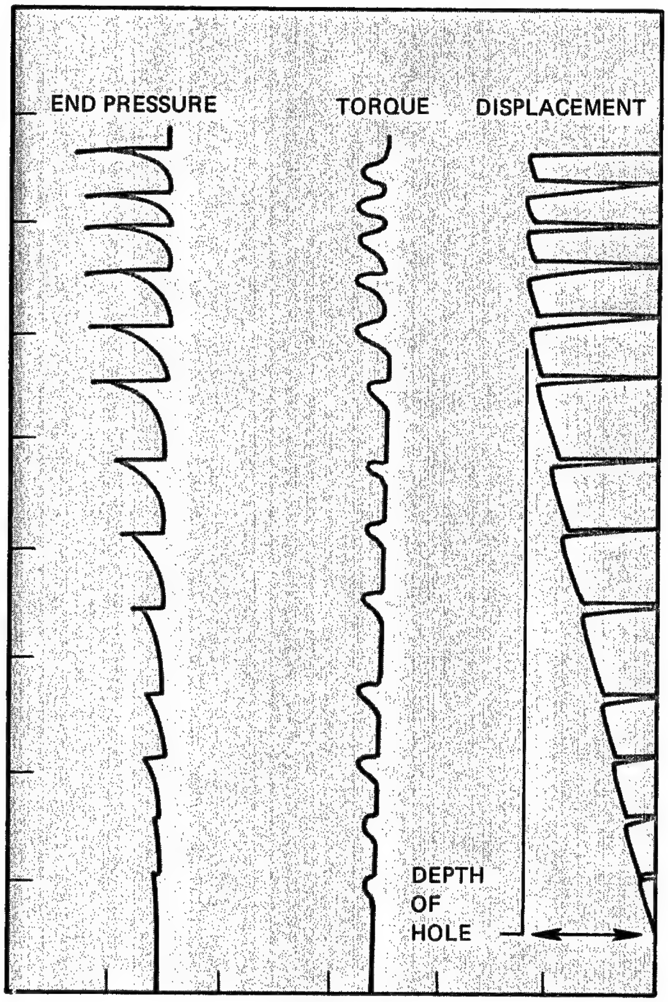


Figure 2

Modifications Satisfy Requirements

How was all of this accomplished? The 300A design involves several modifications of the 300M. A special d-c powered spindle motor provides variable speed to 10,000 rpm, with a minimum of 10 inch ounces of torque at 5,000 rpm. This motor is housed in a larger, redesigned air bearing quill. A proximity switch installed inside the quill counts revolutions of the spindle motor. This count is used for the spindle rpm indicator. A rack and pinion drive supplies the in and out action of the quill. An ElectroCraft 550 series motor generator drives the quill. This motor was chosen because of its 100:1 controllable speed variation and its capability of monitoring current.

A slide limit switch directs the controller for rapid and slow infeed with the following control sequence. When the drill retracts to clear chips, a rapid retract and rapid advance device clears and returns the drill to within 0.020 in. of its position when retracted. The drill infeed then switches to a slow drilling mode and continues to drill where it left off. The slide limit switch provides the 0.020 in. pretravel signal to the control.

Westhoff has also attached a three axis digital readout on the drill; two of the axes indicate drill position and the third indicates drill depth. A preset option is fitted to control drill depth, with an output signal from the digital readout available to control a depth stop on the electronic console.

Plug In Relays Provide Control Logic

The electrical design uses mechanical plug in relays for control logic. These relays offer several advantages—standard parts are readily available; service is easy; and direct switching is provided with no need for power

amplifiers, which would be required with solid state logic. Three power supplies are used in the basic circuit:

- A variable voltage and current, 0-40 V d-c, 0-6 amp, TeleDynamics Brute I to power the spindle motor
- An ElectroCraft 550-0 closed loop d-c supply for the infeed/retract motor
- TeleDynamics DPS series, open frame, 12 V d-c supply for relay coil power.

Figure 3 illustrates the relay control logic sequence.

The spindle and infeed motors can be monitored for speed or current using a selector switch. The monitoring

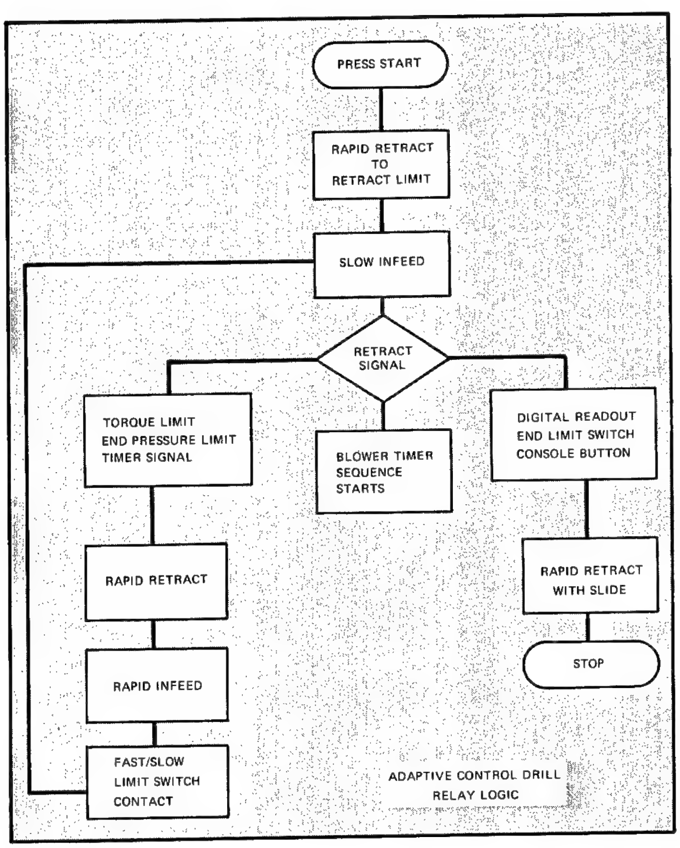


Figure 3

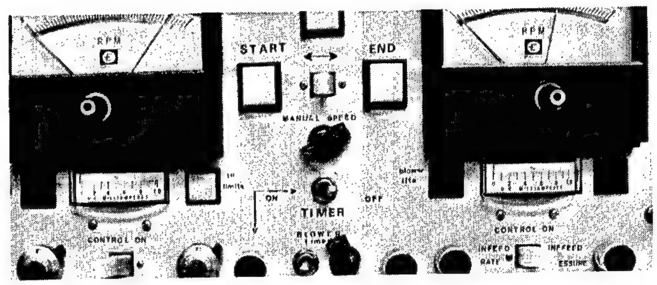


Figure 4

meters are high and low limit meter relays with the relays used as inputs for retract commands to the logic circuits. With this arrangement, the drill operator can retract on a high limit when monitoring the current of the spindle or infeed motor, or on a low limit when monitoring spindle speed or infeed rate. Details of the front control panel are shown in Figure 4.

Additional Features of the Drill Control

- A **jog switch** that is a convenient left/right momentary spring center return lever switch. The jog function allows rapid controllable positioning of the drill for setup and depth stop determinations.
- **Speed/voltage and pressure/current potentiometers,** conveniently located on the left and right side of the console directly below the associated meter relay.
- A **timer circuit** that gives an automatic retract signal from 1 to 30 seconds after drilling begins. This control provides an automatic pecking feature for chip removal when materials are being drilled that don't require torque or end pressure monitoring.
- A **blower timer circuit** that provides a variable timed signal that is activated when the drill starts to retract. This signal, available as isolated contacts on the rear of the control console, activates an air solenoid to blow away chips and cool the drill during retract.
- **Recorder** outputs for spindle and infeed motor speed and current as well as drill replacement data. As noted, the recorder outputs have proven very useful for drill development studies.

The drill console, shown in Figure 5, is housed in a BUD enclosure with all inputs and outputs provided through jacks on the rear panel.

Thus far, G.E. has only undertaken drill optimization studies to meet its in-house needs. However, future studies of a more far reaching nature are planned. Funding for such studies is being solicited from various sources including military and industrial users. For further information or details on the adaptive control microdrill construction or capabilities, contact

Manager of Manufacturing Engineering
General Electric Company
Reentry and Environmental Systems Division
3198 Chestnut Street
Philadelphia, PA 19101
(215) 823-2073.

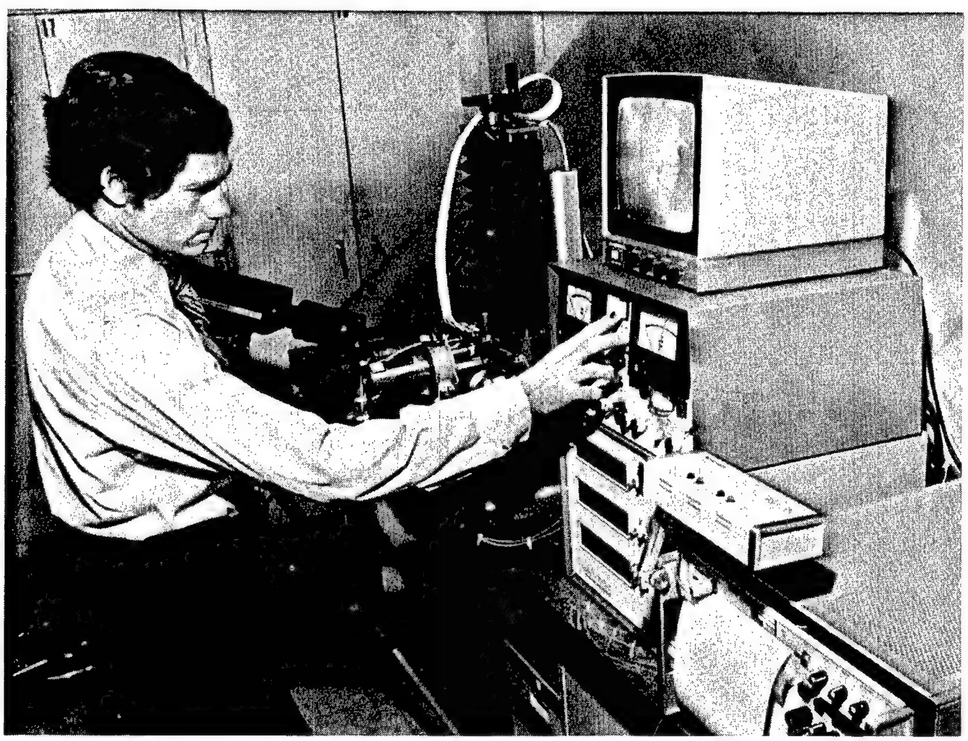
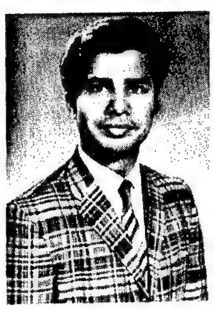


Figure 5

Machinability Data Systems

Required for Effective Cost Reduction



VIJAY TIPNIS received a diploma in Mechanical Engineering from V.J.T.I. (Bombay, India) in 1958, an M.S. in Management at Case Western Reserve University in 1970, and an Sc.D in Mechanical Engineering from M.I.T. in 1965. From 1964 to 1973 he was Head of the Machinability Research and Development Department at Republic Steel. In 1973 he came to Metcut Research Associates Inc., where he is Vice President and Director of Manufacturing Technology. He has been very active in the areas of metal cutting, machinability, processing economics and computer aided manufacturing; he is the author of over 30 papers on such subjects. Dr. Tipnis is a member of ASME, ASM and SME.

MICHAEL FIELD received a B.S. in Mechanical Engineering from the City College of New York in 1937, an M.S. in Mechanical Engineering from Columbia University in 1938, and a Ph.D. in Physics from the University of Cincinnati in 1948. From 1938 to 1948, Dr. Field was Research Engineer at The Cincinnati Milling Machine Co., where he was engaged in machinability and machine tool studies. From 1948 to date, he has been with Metcut Research Associates Inc., where he is President and General Manager. Dr. Field's activities have included manufacturing engineering investigations in commercial and aerospace manufacturing, metal cutting, surface integrity of metals, and mechanical testing. He is the author of over 100 papers in the field of machining and metal cutting. Dr. Field is a member of SAE, ASM, AAAS, SESA, AIAA, SME, AOA, SAMPE, and Sigma Xi. He also has received the following honors: 1966 "Engineer of the Year" by the Technical and Scientific Societies Council of Cincinnati, 1968 "Gold Medal Award" by ASTME, 1969 "Distinguished Alumnus Award" by the University of Cincinnati, 1968 "Joseph Whitworth Prize" by the Institution of Mechanical Engineers/England, 1970 ASM Fellow, and 1971 "William H. Eisenman Award" by ASM/Cincinnati Chapter. He was elected to the National Academy of Engineering in 1976.

This issue of the *Army Mantech Journal* emphasizes innovations in machining methods aimed at improved quality and cost reductions.

With machining of commercial industrial, and military hardware costing about $60 billion annually in labor and overhead (Table 1), potential savings are huge. To take full advantage of these innovations and to develop and apply machining operations in the most cost effective manner, an effective machinability data system is required in conjunction with sound economic analysis techniques. Development of the data system demands careful integration of data generation, data analysis, and data application. In order to provide a more complete overview of machining operations, let us consider briefly why effective data systems are important and outline a few details on how to develop and apply such systems.

The increasingly stringent design and performance requirements of modern technology and the growing use of high strength materials exert constant pressure for the development of improved machine tools, cutting tools, and machining techniques. These needs cannot be met effectively without accurate, easily applied data on both input and output functions of the process.

Hard Data the Key

The pertinent input parameters are cutting tool material and geometry, cutting speed, feed, depth and width of cut, and the work material and its pertinent characteristics, such as heat treat condition, hardness, and

[illegible]	2,692,000
[illegible]	$10-12 Per Hour
[illegible]	8 Hours
[illegible]	250
[illegible]	[illegible]
[illegible]	$53,840,000,000 $64,608,000,000
Total annual cost in United States	$60,000,000,000

Table 1

chemistry. The output functions include tool life, surface finish, forces between the tool and workpiece, surface integrity, accuracy, and power characteristics of the operation.

Historically, manufacturers have relied on the experience of the machinist to select the optimum machining conditions. During the past decade, many job shops have complemented the machinists' skills with process planning and scheduling. However, maximum economic benefits are rarely achieved unless individual machining operations are based on actual machining data and economic evaluations of the alternatives.

Data Derived From Experience

The modern approach is to convert the experience based machining technology to a data based technology. A modern machinability data system is built on recognition that

- Machining data can be generated and applied at three levels:
  - Starting recommendations
  - Plant specific data, either historical or from production trials
  - Operation specific data developed in the form of a mathematical model.
- Machining technology is steadily advancing, hence the data must be constantly updated. This is done most easily with a computerized data base.
- The appropriate machining data must be accessible to make important manufacturing decisions for
  - Process planning
  - Scheduling
  - Cost estimation
  - Purchasing decisions.
- Data from the actual machining performance on the shop floor must be fed back to the data base and reconciled with data already there.

Handbooks, Work History Next Level

The simplest form of data base is machining data handbooks. Such handbooks usually provide data for proprietary products, such as cutting tools, or for specific types of work materials. Other handbooks are directed toward specific machining operations. Typical handbook data is shown on the page from Metcut's Machining Data Handbook shown in Figure 1.

Often handbooks on particular machining operations, workpiece materials, cutting tools, and cutting fluids used by a specific company are compiled from the general handbooks. Such handbooks form an important source of common data to be used by the planners, estimators, purchasing agents, and shop personnel. They comprise the next level of data base.

These handbooks sometimes are improved by compiling historical data on actual shop performance on critical groups of parts. A computerized data system can automate the handling of such data.

Shop Trial Data Most Valuable

Often neglected in this regard are shop trial data generated within a company, which can be readily

Turning, Single Point and Box Tools

MATERIAL	HARD-NESS BHN	CONDITION	DEPTH OF CUT inches	HIGH SPEED STEEL TOOL			CAST ALLOY TOOL		CARBIDE TOOL			
				SPEED fpm	FEED ipr	TOOL MATERIAL	SPEED fpm	FEED ipr	SPEED - fpm BRAZED	SPEED - fpm THROW-AWAY	FEED ipr	TOOL MATERIAL
14. CARBON STEELS, CAST (cont.) Medium Carbon ASTM A352: Grade LCB ASTM A356: Grade 1 1030 1040 1050	125 to 175	Annealed, Normalized or Normalized and Tempered	.150	115	.015	M2, M3	130	.015	360	450	.020	C-6
			.025	155	.007	M2, M3	170	.007	450	600	.007	C-7
	175 to 225	Annealed, Normalized or Normalized and Tempered	.150	95	.015	M2, M3	110	.015	325	400	.020	C-6
			.025	125	.007	M2, M3	145	.007	430	525	.007	C-7
	250 to 300	Quenched and Tempered	.150	70	.015	T15, M33, M41 Thru M47	85	.015	290	350	.015	C-6
			.025	90	.007	T15, M33, M41 Thru M47	105	.007	375	450	.007	C-7
15. ALLOY STEELS, CAST Low Carbon ASTM A217: Grade WC9 ASTM A352: Grade LC3 ASTM A426: Grades CP2, CP5, CP5b, CP11, CP12, CP15, CP21, CP22 1320 2315 2320 4110 4120 4320 8020 8620	150 to 200	Annealed, Normalized or Normalized and Tempered	.150	100	.015	M2, M3	130	.015	380	465	.020	C-6
			.025	130	.007	M2, M3	160	.007	465	575	.007	C-7
	200 to 225	Annealed, Normalized or Normalized and Tempered	.150	95	.015	M2, M3	100	.015	350	410	.020	C-6
			.025	125	.007	M2, M3	130	.007	425	525	.007	C-7
	250 to 300	Quenched and Tempered	.150	65	.015	T15, M33, M41 Thru M47	80	.015	275	350	.015	C-6
			.025	90	.007	T15, M33, M41 Thru M47	100	.007	340	425	.007	C-7

Figure 1

COST FOR TURNING AISI 4340 (300 BHN) WITH CARBIDE												
Cut speed: 470 ft/min				Feed: .010 in./rev				Tool life: 15 min				
Type Tool	Feed Cost, $	Rapid Travel, $	Load Unload, $	Set Up, $	Tool Change, $	Tool Depreciation, $	Tool Sharpening, $	Rebraze, $	Tip Cost, $	Grind Wheel, $	Total Cost, $/piece	Prod Rate, pieces/hr
Brazed	.55	.04	.34	.15	.18	.05	.55	.06	.01	.01	1.98	7.0
Throw-away	.55	.04	.34	.15	.01	.00	—	—	.04	—	1.15	8.0

Figure 2

collected and stored. Manufacturing and tool engineers often conduct extensive trials to investigate different cutting tools, cutting fluids, and speeds and feeds to improve a given operation. Systematic records of these trials, indicating conditions that did and did not work, form a valuable data base for planning future operations without having to repeat the trials. The introduction of computer numerical control, direct numerical control, and adaptive control provides new opportunities to develop automated systems for the collection and storage of shop performance data.

The most advanced and specific form of machining data is that generated during planned experiments, either in a shop laboratory or on a shop floor. Whenever possible, researchers should design such experiments for statistical analysis. These experiments provide the most information at the lowest cost. Numerous studies over the past decade have sought to develop systematic methods to statistically design tool life experiments and to interpret and apply the data obtained.

Shop Records to Mathematical Model

Equations that relate output functions to input parameters using computerized stepwise regression programs are available. Using them, we can establish concise and statistically valid tool life estimates with a minimum number of experimental tests. Moreover, the mathematical relationship can be adapted to specific shop situations by introducing actual shop performance into the mathematical model.

Selecting the optimum machining conditions for a given operation also requires an economic analysis. One approach to economic analysis calculates cost per piece, production rate, and pieces per hour for individual machining operations. The equations for cost and production rate, for example, have been developed for turning, milling, drilling, tapping, and reaming. Computer programs for handling these equations are available. Programmable calculators can also be used for cost and production rate analysis. Figure 2 illustrates a typical computer printout of cost factors and production rate in turning.

Graphic Terminal Latest Step

Development of a still more advanced computerized cost and production analysis technique is under way. This approach uses a time shared graphic terminal allowing integration with NC programming. A flow chart of this in-

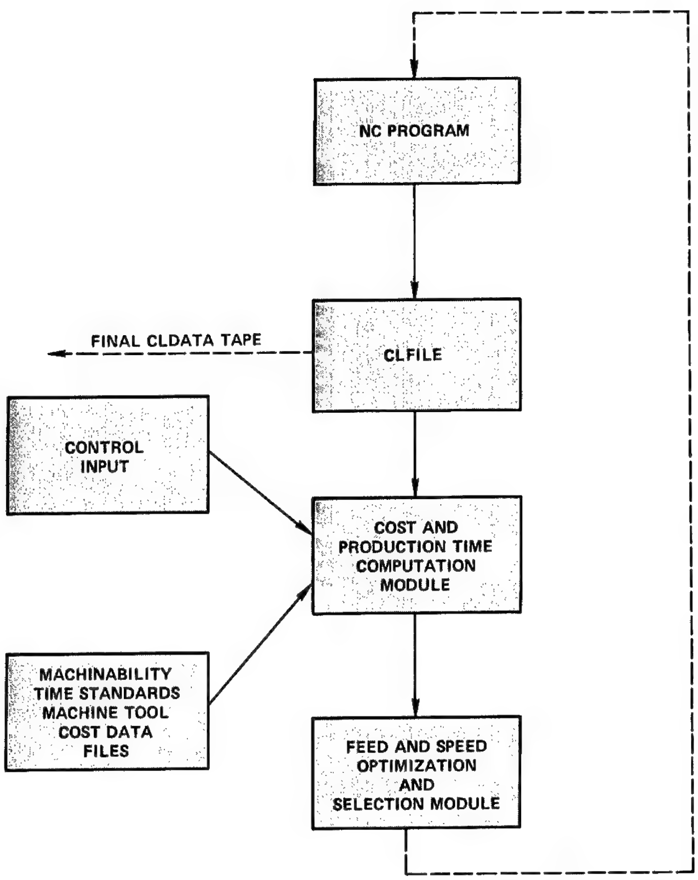


Figure 3

tegrated approach is shown in Figure 3. Input data to the model consists of the workpiece material, width of cut, the machine tool code, machinability, time standards, the machine tool, and costs. The computer displays and prints out an economic analysis, as illustrated in Figure 4 for an end milled actuator arm. The data is arranged by the computer in order of increasing total cost per piece.

The program also provides a printout breaking down all the elements that contribute to cost—i.e., the cost of feeding, rapid traverse, load and unload, setup, tool change, and total tool costs.

Thorough Analysis Mandatory

We should note here the importance of performing a cost analysis **before** any cost reduction is achieved. This is extremely important because (1) the total cost to machine a given part may be so low that further cost reduction would be unwarranted and (2) the high cost elements must be identified before performing any cost reduction. Too often, we find that the first thing a manufacturing engineer does to reduce costs is change feeds and speeds of the tool. In many cases, however, the feeding cost is only a small percentage of the total cost and is not the place to look for reductions.

The graphic terminal referred to above has been programmed to accept data from a sophisticated mathematical model of tool life. Such data is utilized to make a cost and production analysis and to determine the optimum cutting conditions based on cost or production rate.

PRIMARY ECONOMIC ANALYSIS

Operation: Profile End Mill Actuator Arm
Cutter: 0.75 Inch Diam, HSS End Mill

Feed, In/Tooth	Speed, Ft/Min	Tool Life, Min	Total Cost, $	Production Time, Min
.005	190	170	.69	1.93
.004	190	250	.70	2.06
.004	210	200	.70	2.00
.004	240	140	.72	1.94
.005	240	95	.76	1.87
.004	295	60	.92	1.97
.002	190	190	.96	2.88
.002	240	70	1.08	2.68
.005	295	35	1.17	2.05
.002	295	20	1.87	3.00

Figure 4

Fiber Optics Detect Pump Malfunctions

Wider Uses Foreseen

MICHAEL HALIK has had extensive experience in the field of chemical instrumentation, both in the research laboratory as well as the manufacturing area. Originally, he was with the Feltman Research Laboratories at Picatinny Arsenal, where he adapted and modified physicochemical research instrumentation for application to complex research and development problems. Since he joined the Manufacturing Technology Directorate at Picatinny Arsenal in 1969, Mr. Halik has headed programs involving the development of specialized process control instrumentation with specific application to new, modernized ammunition manufacturing processes. He received his B.S. Degree in Chemistry from Upsala College in 1951, after which he undertook extensive graduate work in chemistry and physics at Stevens Institute of Technology and Fairleigh Dickerson University Graduate School.

Engineers at the U.S. Army Armament Research and Development Command's Large Caliber Weapons Systems Laboratory used fiber optics to develop a safe, inexpensive process control system for an explosives loading operation. This system automatically detects costly malfunctions in the diaphragm of Pulsafeeder pumps used in weapons loading and then stops the pumps. The pumps are shut down when photodetectors sense changes in light absorption of hydraulic pump oil that becomes contaminated with TNT from the explosive compound. As little as 0.5 percent TNT in oil will activate the pump shutdown sequence.

The concept has wide potential application; proper development could save both time and money in many manufacturing processes. In the explosives loading application, the system detects visible light. With proper light sources, detectors, filters, and fiber optic material, it operates equally well in both the infrared and ultraviolet regions. Thus, the basic design is useful for controlling any closed system equipment in which changes in the internal chemical environment flag a malfunction. Lets look more closely at the system now in use.

Eases Difficult Inspection Problems

Detecting malfunctioning components in manufacturing process equipment is always difficult. This is particularly true for totally enclosed components that cannot be seen unless the process is shut down and the machine taken apart. Such shutdown is both costly and time consuming.

The Pulsafeeder pump used with the continuous melt pour process for weapons loading presents such a problem. This pump transfers molten explosive from a continuous melter to a volumetric loader. It employs a teflon diaphragm with a check valve arrangement at both ends (Figure 1). Periodic, pulsating hydraulic pressure is applied to the diaphragm to produce a squeezing action. In combination with the check valve arrangement, this forces the molten explosive through to the volumetric loader. The diaphragm sometimes fails due to the constant flexing and to action of the oil at the required elevated temperature (90-100 C). When this occurs, hydraulic oil enters the explosive line and is contaminated.

There was a need to detect such malfunctioning early and shut the pump down immediately. But with the totally enclosed system, a break could not be detected externally. Therefore, a system was sought that could monitor the diaphragm in-place automatically and continuously.

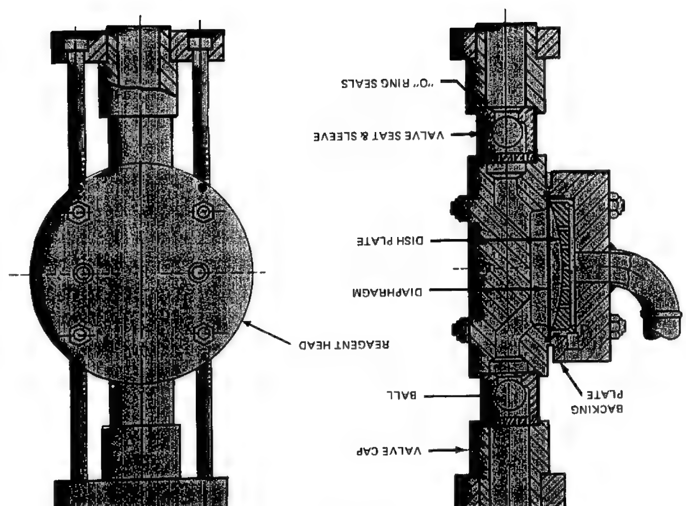


Figure 1

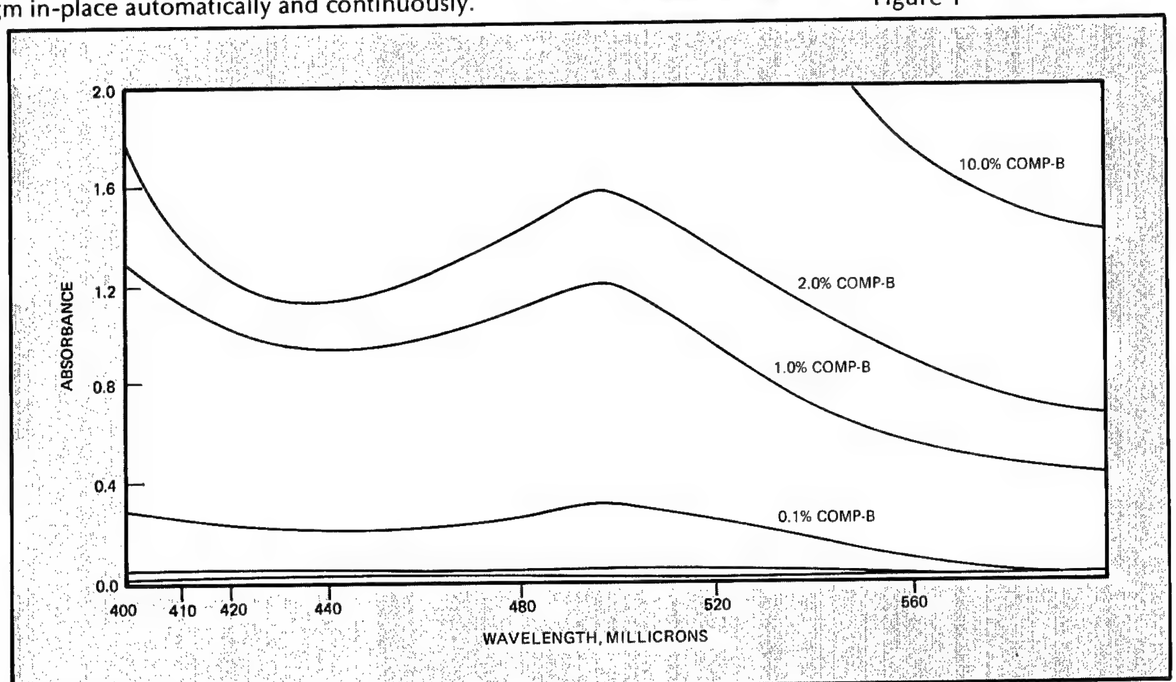


Figure 2

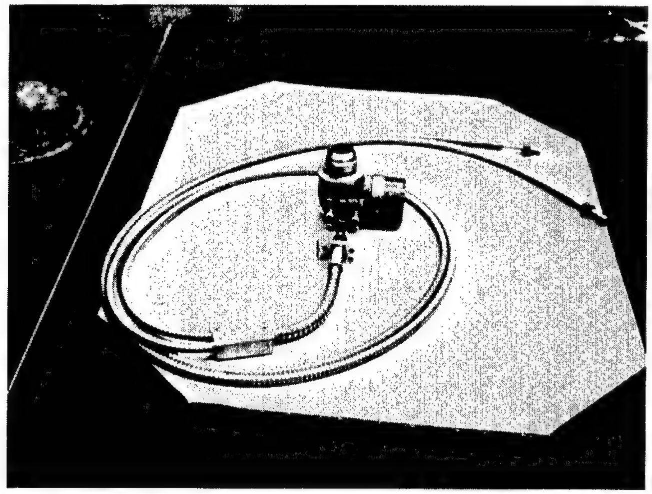


Figure 4

Color Changes Show Contamination

Initial studies revealed that the color of the hydraulic oil changed radically whenever it came into contact with the Composition B explosive fill. This was especially true at elevated temperatures. Further investigation indicated that this change resulted from a chemical reaction between the hydraulic oil and the TNT in the explosive composition. The color change occurred only when TNT was present in the hydraulic oil; prolonged heating of the oil by itself did not cause the color change.

These findings indicated that a sensitive malfunction control system based on detection of this color reaction was both feasible and practical. Particularly attractive was the low cost and reliability offered by an on line photometric system operating in the visible region of the spectrum.

Optical System Does the Job

A spectroscopic examination of contaminated oil revealed that maximum absorption occurred at a wavelength of approximately 500 nm, as shown in Figure 2. Therefore, a system was designed using optical filters to optimize detection and measurement of radiation in this 500 nm region.

Figure 3 illustrates the system design. The optical system consists of a visible light radiation source, a bifurcated fiber optic light guide with a reflective sensing end, and two photodetectors arranged in a bridge circuit. Figure 4 shows the fiber optic light guide and the elbow into which it is mounted.

HYDRATUBE LEAK DETECTOR

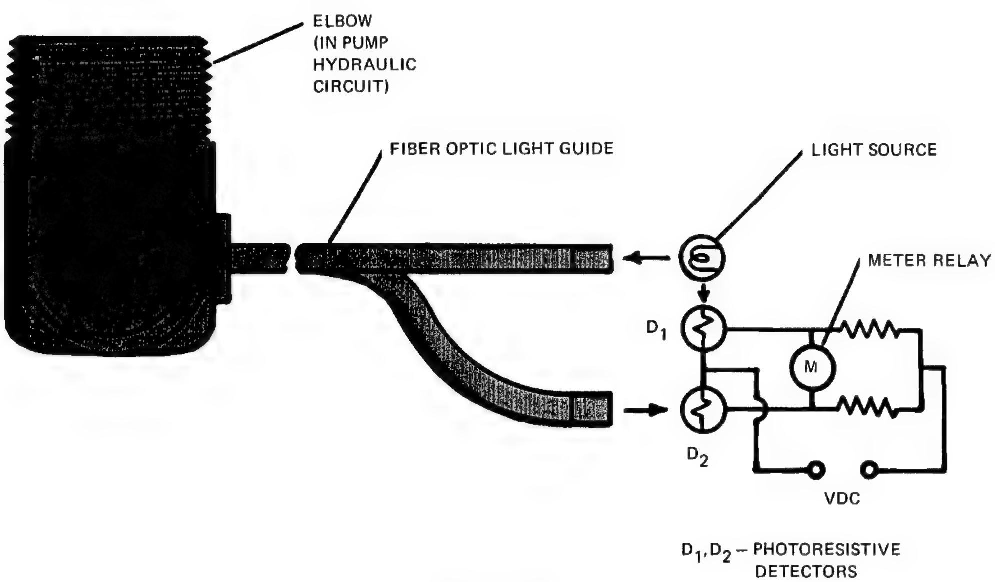


Figure 3

R_2-D_2 Team Up

A diagram of the electric circuit for the system is shown in Figure 5. The photodetectors are resistive elements forming two arms of a standard Wheatstone Bridge circuit. The potentiometer R_2 forms the other two arms of the detection circuit. R_2 is adjusted so that the bridge is balanced and no current flows through R_1. Under this condition, the meter relay (M) reads zero. This is the normal state when photodetector D_1 is looking at the light source directly and D_2 is looking at the light that has passed through the fiber optic light guide and unadulterated oil.

When the diaphragm leaks, contaminated oil absorbs some of the light that normally passes through the fiber optic light guide. Detector D_2 therefore receives less light, causing an imbalance in the bridge circuit. The bridge imbalance in turn causes current to flow through R_1 and the meter relay. This current activates the 24 volt power relay, cutting the power to the pump and shutting it down. Tests of the detection system have shown that a concentration of just 1/2 percent TNT in the hydraulic oil will cause enough absorption to shut off the pump.

Safe, Continuous Monitoring

This control system constitutes a continuous monitoring device for detecting changes in light absorption of the hydraulic oil due to contamination by TNT. The range selector can be used to monitor a contamination range from 0-20 percent TNT. Whenever the reading on the meter passes the preset point, indicating an increase in light absorption by the pump oil, pumping is stopped.

From a safety standpoint, the control system is totally isolated from the process, so no electrical hazards exist.

As noted earlier, the same design principles also could be used to monitor infrared and ultraviolet radiation, allowing application of the process to a wide variety of other closed systems.

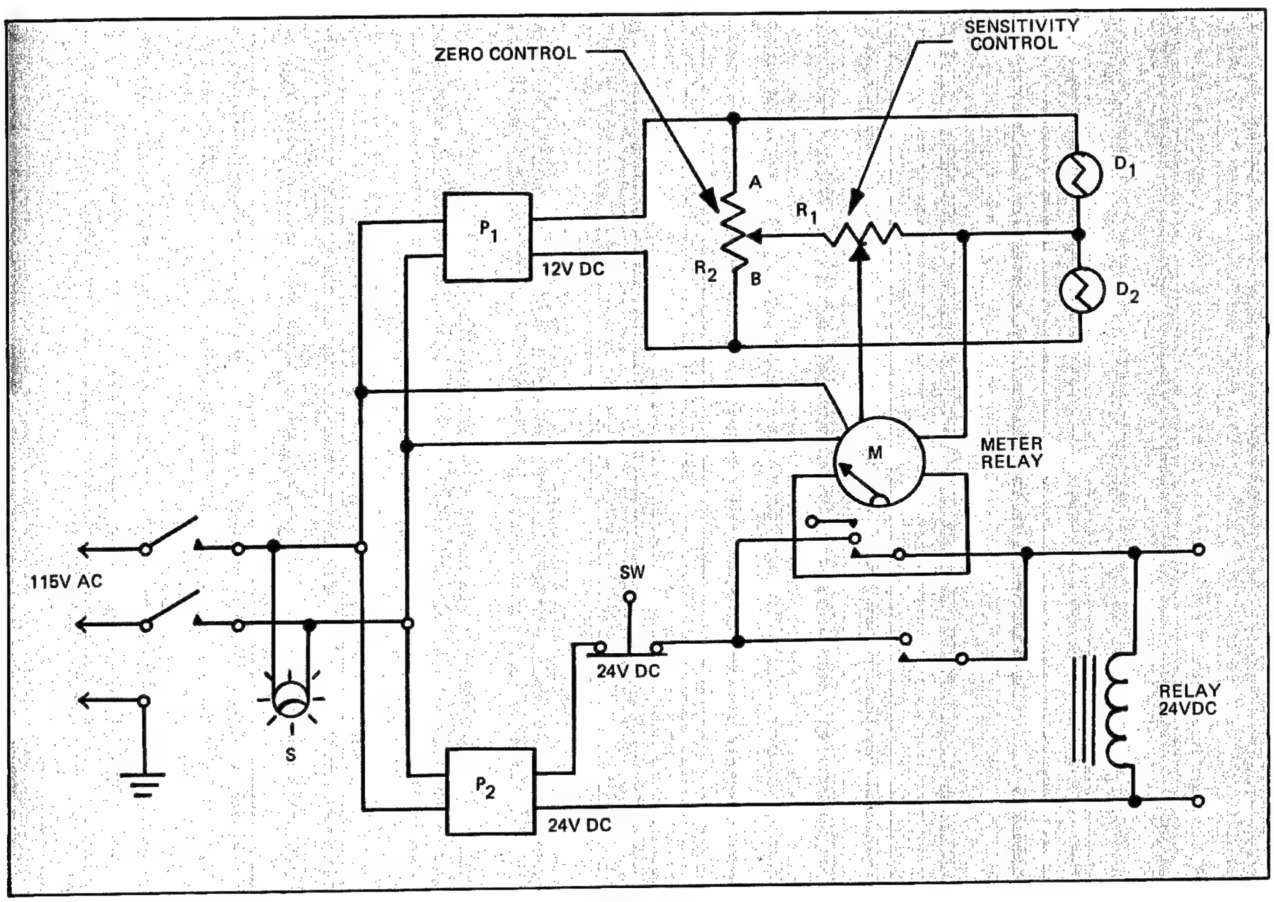


Figure 5

Brief Status Reports

Water Jet Cutting. A water jet cutting system was recently installed with pressure capability of 60,000 psi. The primary purpose is to cut nonmetallic materials for airframe structures such as fiberglass, Kevlar, graphite, rubber, foams, and insulation. Considerable work has been done to develop accessory equipment, techniques, and cutting data on various materials. Advantages, limitations, and comparisons with conventional cutting have been established. For additional information, contact Mr. David Seitz, U.S. Army Materials and Mechanics Research Center, (617) 423-3522 or AUTOVON 955-3522.

Fabrication of a Lightweight Impact Resistant Helicopter Drive Shaft. A tooling system and manufacturing method has been developed for making a composite drive shaft with integral metal end fittings. The tools are easily removable from the cured part and are reusable without any need for refabrication. The manufacturing method utilizes a cocuring process. The resultant drive shafts have excellent dimensional tolerances and are removed from the tools without the need for subsequent machining. Several drive shafts have been made by the method and have been successfully tested at both Lockheed and the Army for static fatigue and damage and ballistic tolerance characteristics. For additional information, contact Mr. Gerald Gorline, U.S. Army Aviation Research and Development Command (314) 268 -6476 or AUTOVON 698-6476.

Guided Boring System. A guided boring system has been developed to detect and automatically correct off course or eccentric boring on long cannon tubes. In the guided boring head, an accelerometer senses eccentric motion and signals a servovalve that produces hydraulic corrective forces to restore the alignment of the boring head with the centerline of rotation. This produces a straighter bore and significantly reduces rework and total machining time. In the prior process of wood pack reaming, straightness deviations of 0.100 inch were considered good, but this process occasionally produced a scrap tube. Guided boring guarantees a straightness deviation less than 0.005 inch—the thickness of a razor blade—and has never produced a scrap tube (each of which would cost 5 to $20,000). Also, one guided boring machine has replaced three wood pack boring lathes, resulting in significant reduction in floor space requirements. Because of the increased accuracy of this process, problems in attaining proper stock distribution after boring have been reduced and smaller diameter forgings can be purchased, again saving material costs. For more information, contact Mr. Gerald Spencer, Watervliet Arsenal, (518) 266-5418 or AUTOVON 974-5418.

Abrasive Machining. An abrasive grinding machine has been developed to machine cylindrical components of breech mechanisms. This machine uses a carbide roll that is contoured the same as the component. The carbide roll crush dresses the form onto the grinding wheel, which in turn removes stock at a rapid rate and produces the desired contour on the component. Using this technique, the machining of a 105-mm M68 breech component is reduced from 1 hour and 15 minutes to just 13 minutes, an impressive 83 percent reduction in time. Much of the high metal removal rate is credited to the cutting surface speed of 11,000 feet per minute, the jet wheel cleaner, and the coolant nozzling that flushes the swarf away from the wheel face. For more information, contact Mr. Gerald Spencer, (518) 266-5418 or AUTOVON 974 -5418.

Benching Device. A production problem occurred when a longitudinal missile guide slot was machined in the 152-mm gun/launcher tube. The difficulty was the "benching" or removal of sharp corners where the guide slot

intersects the normal helical rifling groove. Workers could neither reach nor see the sharp corners. A remote control and observation tool was designed, using a pneumatic motor with carbide burr attached to a borescope. As a result of implementing this ingenious device, this operation has been reduced by 40 hours to 3 hours per 152-mm gun tube. Total savings (since FY 66) amount to more than $2.4 million, an impressive amount for an investment of only $35,000. For more information, contact Mr. Gerald Spencer, (518) 266-5418 or AUTOVON 974-5418.

Step Threading. Special equipment has been designed to machine the step threads on large caliber breech rings and breech blocks. The "step" or interrupted thread design maximizes the breech block engagement area while minimizing the rotary movement to open and close the breech block. The machine oscillates the breech block back and forth (similar to a washing machine agitator), simultaneously machining two sectors to size. The threading tools, which are mounted 180 degrees apart, are full form tools that contain the necessary teeth to machine all threads of each sector. This new step threader has reduced machining time on the 8-inch M201 breech block by fifty percent, from 7 hours to 3.5 hours. Similarly, a step threader has been developed that machines the internal step threads of the breech ring, resulting in an 8-hour saving per breech ring; the original process took 12 hours. For more information, contact Mr. Gerald Spencer, Watervliet Arsenal, (518) 266-5418 or AUTOVON 974-5418.

Dual Rifling. A dual rifling process that increases 105-mm M68 gun tube rifling production by 40 percent has been implemented recently. Because gun tube specifications require close dimensional control and surface finishing, rifling grooves have always been costly and time consuming to produce. Other attempts to reduce rifling costs were unsuccessful until the dual rifling machine was developed. This machine simultaneously broaches the rifling on two tubes without undue strain on the equipment. Besides the benefit of a 40 percent reduction in costs, additional advantages include reduction of needed floor space, reduction in set up time, and reduction in manpower. For more information contact Mr. Gerald Spencer, Watervliet Arsenal, (518) 266-5418 or AUTOVON 974-5418.

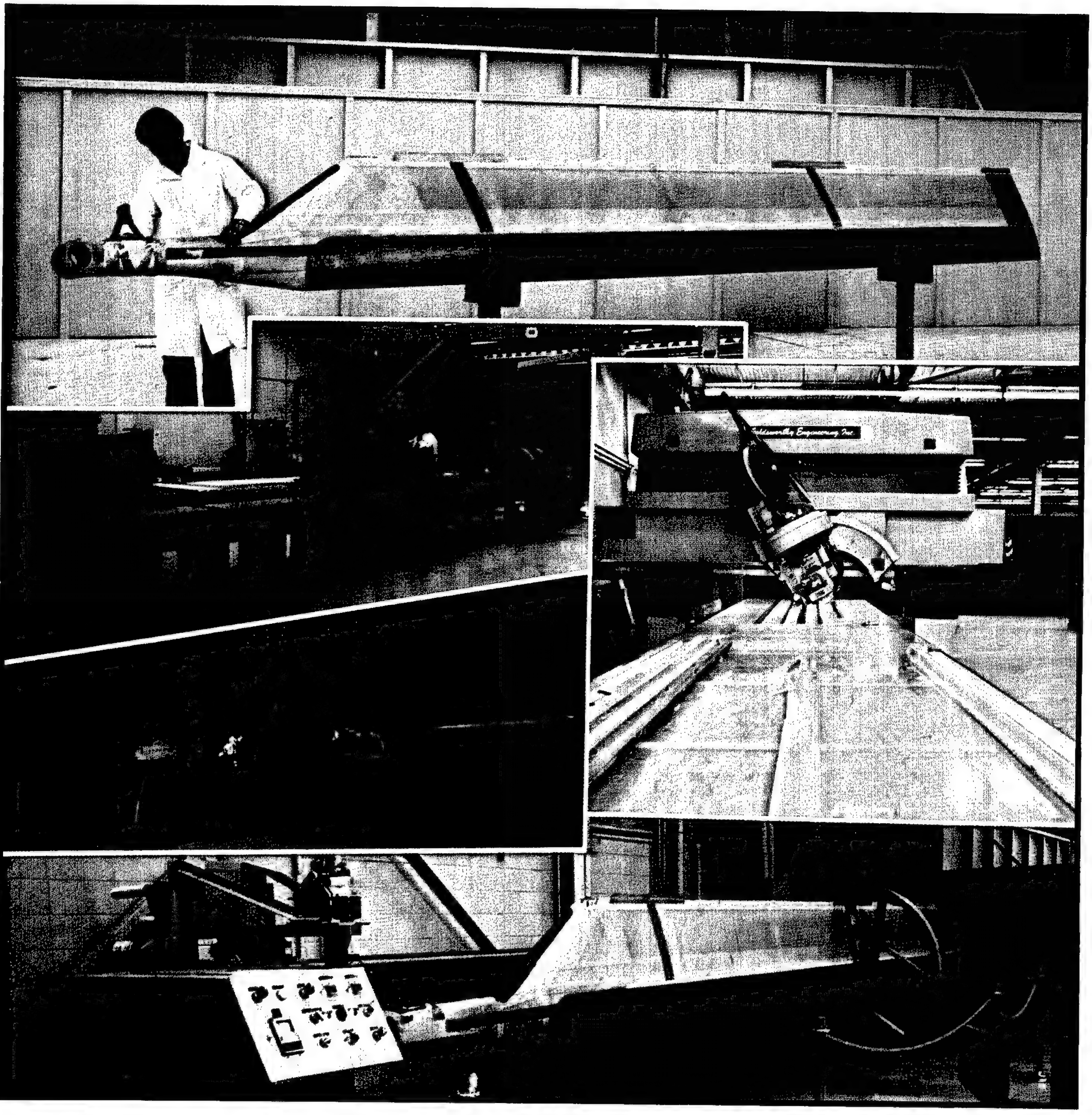
Cartridge Actuated Joggling. A process has been developed to form joggles in aircraft parts using exploding gunpowder as the energy source. Portable tools are used to form joggles at room temperature in stretch formed aluminum extrusions. An automatic machine has been built to form joggles in heat treated aluminum extrusions at elevated temperature. Parts produced by this method have excellent quality, scrap has been minimized, and tooling cost has been greatly reduced. For additional information, contact Mr. Gerald Gorline, U.S. Army Aviation Research and Development Command, (314) 268-6476 or AUTOVON 698-6476.

Hydraulic Autofrettaging And Swaging. Hydraulic autofrettaging and swaging are current permanent bore enlarging techniques which create favorable residual compressive stresses. These techniques have strengthened cannon tubes, increased their fatigue life, and reduced cannon weight, thereby saving material costs and increasing the mobility of weapons. If it were not for this process, cannon tubes would require thicker and heavier walls or multipiece jacketed construction to obtain the same fatigue life as autofrettaged tubes. Besides the improvement in these important performance characteristics, savings to date total nearly $50,000,000. For additional information, contact Mr. Gerald Spencer, Watervliet Arsenal, (518) 266-5418 or AUTOVON 974-5418.

US Army
ManTech Journal

Technology Transfer Assured

Volume 3/Number 1/1978



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US Army
ManTech Journal

Contents

ABOUT THE COVER:

The first U.S. Army CH-47 "Chinook" helicopter fiberglass rotor blades have been successfully manufactured at The Boeing Vertol Company using the automated equipment shown on the cover. The Army-developed Automated Tape Layup System (right center) was the forerunner for a fully automated production system. ATLAS lays up preimpregnated fiberglass tape to form the structural elements of the glass fiber/epoxy composite rotor blades. ATLAS established the basic foundation for development of other production tooling such as the Boeing Production Automated Tape Layup Machine (upper left center) and the Filament Winding Machine (bottom). Numerically controlled, multiaxis fiberglass tape layup equipment has brought productivity increases of 120 to 1 over hand layup techniques, resulting in significant cost reductions in the production of fiberglass rotor blades.

Comments by the Editor


DR. JOHN J. BURKE

This issue of the ManTech Journal features articles describing the achievements of the U.S. Army Aviation and Research Command (formerly Aviation Systems Command)—achievements that are in many cases unique among the Army Commands due to AVRADCOM's special needs. Included among these significant accomplishments are strikingly advanced techniques in bonding and composites fabrication which we think our readers will find most informative and interesting. It is our hope—as it always has been in the past—that readers will be able to pick up something new which they will be able to apply in their own operations.

In his overview of AVRADCOM's activities in advanced manufacturing technology, Major General Story Stevens points out, as have previous authors, the impact of conferences on new manufacturing techniques. No other Army Command has been more effective than AVRADCOM in working with contractors who possess special capabilities—in their case, those who lead in airframe and engine manufacturing technology. The manufacturing technology conference has played a significant role in the Command's effectiveness in developing this relationship with contractors, as General Stevens' comments indicate.

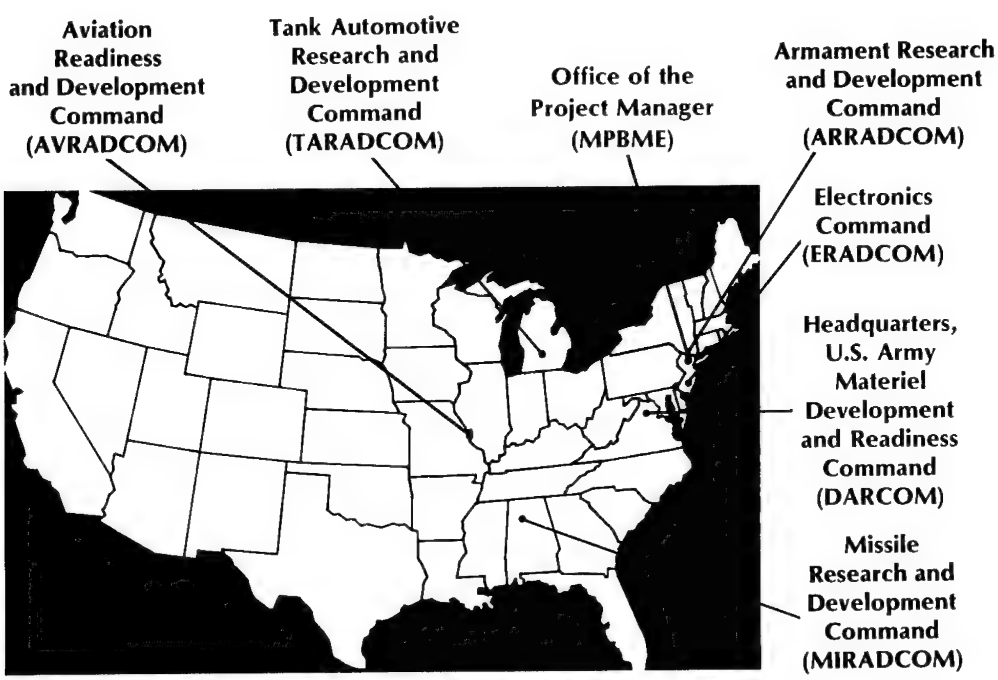
Several other articles in this issue of the ManTech Journal point also to new procedures that provide considerable energy savings when compared with normal manufacturing techniques. Examples are the new processes using ultrasonic and diffusion bonding and the development of the new hot layup technique for fabrication of composite components. Savings of energy will continue to receive emphasis by all the commands of the Army as they strive to offset continued shortages of fuel and rising prices of these commodities. Again, the nation has been hit hard by an unusually severe winter, and these new developments in the manufacturing area that will save fuel and costs will have a beneficial effect on our energy use nationally.

Issues of the ManTech Journal for the remainder of this year will provide readers with an insight into the Army's achievements in Materials Testing, Casting, and Joining, with 1979 topics highlighting efforts on Composites, CAD-CAM, Group Technology, and Electronics. The next issue for this year—featuring Materials Testing—will cover new quality assurance technologies such as ultrasonic holographic inspection, X-ray fluorescence, microwave testing, X-ray scintillation gaging, and faster cannon barrel in-

spection, and also fuze testing and NDT personnel training. Included will be a special brace of articles on the SCAMP (Small Caliber Ammunition Modernization Program) facility at Independence, Missouri. The automated quality assurance and inspection systems in operation at that production facility are the most advanced in the world and undoubtedly will be studied by many manufacturing engineering people throughout the world for transfer of these technologies to other advanced manufacturing operations.

In essence, we feel the upcoming issue on Materials Testing will offer comprehensive information not obtainable in any other publication, and we are looking forward to reader response to that information.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



MAJOR GENERAL STORY C. STEVENS, Commanding General, U.S. Army Aviation Research and Development Command, was born in Kentucky in 1927. Commander of AVRADCOM since July 1977, General Stevens had served since June 1976 as Deputy Commanding General and from July 1975 as Deputy Commanding General for Acquisition at this command, then the Aviation Systems Command. An experienced fixed wing and rotary wing pilot with the Calvary and the Corps of Engineers, respectively, General Stevens has served in Korea, Japan, Viet Nam, and Germany during his career as an officer, which began in 1946 following Officer Candidate School. He received a B.S. in Chemical Engineering from Purdue University in 1954, followed by a B.S. and M.S. in Aeronautical Engineering from Georgia Tech University in 1958. He later taught thermodynamics and fluid mechanics at the United States Military Academy until 1964 after attending the Command and General Staff College in 1960. General Stevens has served in the Materiel Command and on the Office of the Chief of Staff of the Army, where he was Systems Analyst and Chief of the Aviation Division in the Weapons Systems Analysis Directorate. He later served in transportation and logistics groups and also in the Directorate of Research, Development, and Engineering. He attended the National War College in 1971; upon completion, he served as the Comptroller, HQ, Military Traffic Management and Terminal Service, Washington, D.C., until he assumed command of the 1st Support Brigade in Mannheim, Germany in July 1973, with the additional duty of Community Commander.

Industry Conference Plays Key Role

Five Year Investment Plan Developed

An article in the first issue of ManTech Journal (Fall, 1976) outlined the Manufacturing Methods and Technology (MM&T) goals and program plans for the Army Aviation Research and Development Command (AVRADCOM)—then called the Aviation Systems Command. I would like to review a few important points from that discussion and then bring you up to date on plans for the AVRADCOM MM&T program—plans which have evolved from an important conference held in November 1977.

Private Development Funded

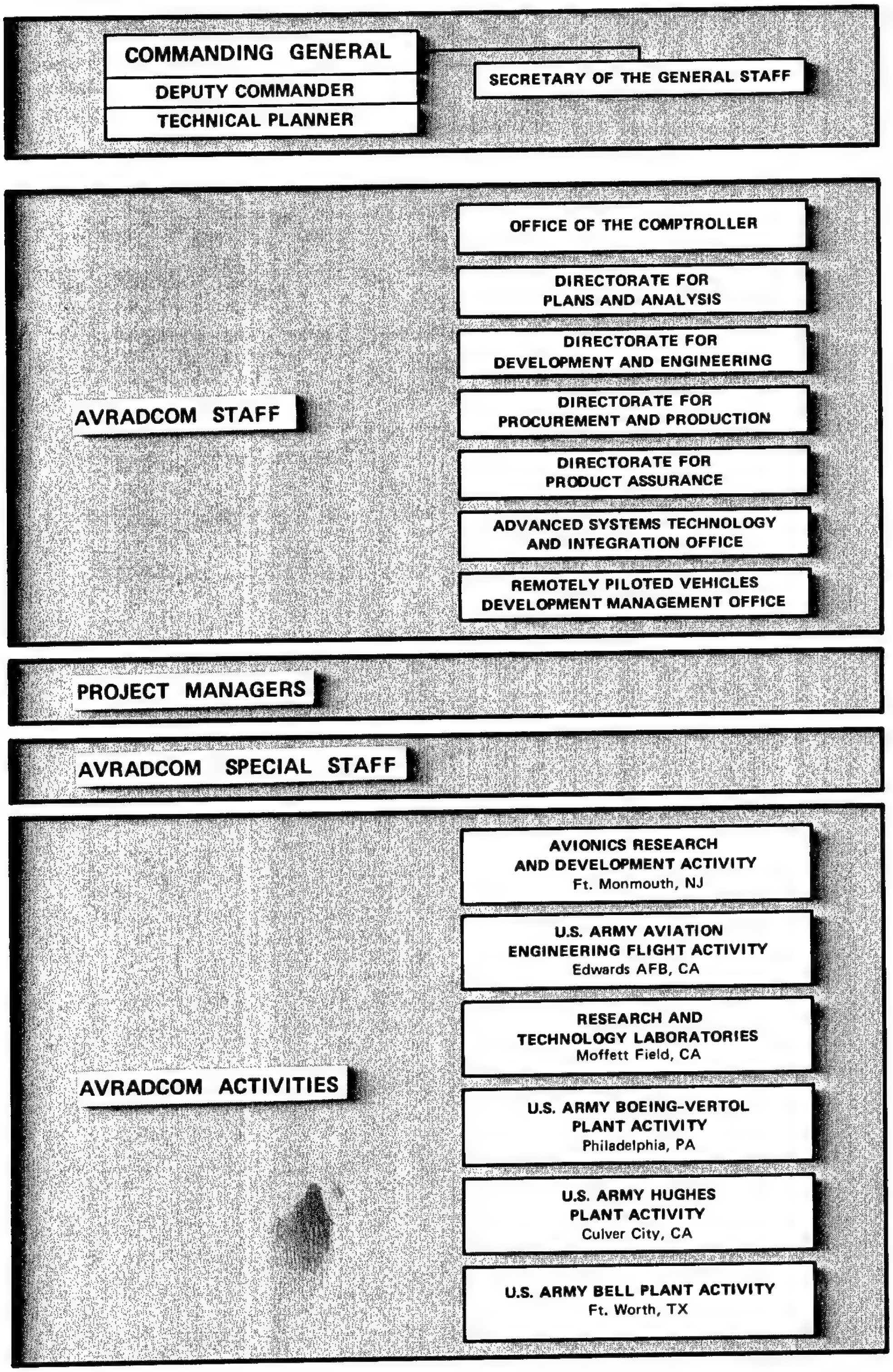
AVRADCOM relies largely on private airframe and engine contractors to develop new manufacturing technology. Whereas this was done before the current MM&T effort primarily through internally funded contractor programs, AVRADCOM now sponsors programs designed to develop and apply specific new manufacturing techniques. This approach provides greater incentive to the contractor, and it insures transfer of the technology to AVRADCOM. AVRADCOM then can direct further refinement, development, and wide application of the technology.

Through its MM&T programs, AVRADCOM is seeking improved manufacturing methods, processes, and equipment for production of Army aircraft. The programs are aimed at cost reduction and improved reliability and maintainability. MM&T projects have a clear application to current or future aircraft production, ensuring that successful efforts will lower acquisition and life cycle costs.

Conference Objectives Defined

In order to help AVRADCOM develop a five year manufacturing investment plan, and to define future MM&T efforts, DARCOM sponsored an Army Aviation Manufacturing Conference in November, 1977. Participants in this working conference included both civilian and military personnel knowledgeable in aviation manufacturing problems. The primary objectives were to identify major cost drivers and problem areas, obtain proposals, and define priorities based on the Army's requirements and potential

U.S. Army Aviation Research and Development Command



payback. The conference was one step toward the ultimate goal of reducing Army aviation systems costs. The significant conference output was a list of recommended potential projects for AVRADCOM's use in planning future investments in manufacturing technology.

The carefully structured working conference format provided an excellent forum for exchange of ideas. Separate panels worked in six aviation technology areas (airframe, avionics/fire control, drive system, engine, rotor system, and subsystems). Each was chaired by someone from a pertinent sector of the aviation industry.

Several months prior to the conference, AVRADCOM requested MM&T project proposals from all recognized aviation oriented firms or organizations. The proposals were collected, published by panel area, and distributed to panel members well in advance of the conference. Panel review of the proposals prior to the conference stimulated more in-depth analysis. At the conference, each proposal was presented orally to the cognizant panel and discussed in a question and answer session. Following review and evaluation, each panel prepared a prioritized list of MM&T projects. The evaluations were based on ease of application, risk, life-cycle cost, uniqueness, safety factors, and potential for pollution abatement and/or energy savings. Panel chairmen then met to consolidate these individual recommendations into a unified conference position and presented this to the conference attendees at the closing session.

Five Technologies Targeted

As a result of the conference, AVRADCOM designated five specific technology advances for immediate funding and set aside $1 million of FY 78 funds for this purpose. They included

- Superplastic Forming of Titanium
- Increased Producibility of Phased Array Antennas
- Fabrication of 4340 Electrolytic Slag Remelt (ESR) Steel
- Castings of High Strength, Low Cost Titanium
- Powder Metallurgy of Hubs and Disks.

One project was developed for each of the technology areas cited except for casting of high strength, low cost titanium. In this area, two projects were formulated—one for an engine component (an impeller) and one for a rotor component (a rotor hub). During project development, it was discovered that the project related to reducing losses in the production of avionics was not ready for mantech funding due to its R&D status. Therefore, another highly rated avionics project, Production Methods for Multielement Modules, was considered for immediate funding.

These six projects have a combined potential savings of well over $36 million. Each project is described briefly below. The top ten projects from each of the technology areas were evaluated further at AVRADCOM. In addition to the six projects mentioned above that were funded by FY78 funds, fifteen projects have been included in the FY79 program. The remaining projects that passed the scrutiny of the board have become part of the FY80-84 AVRADCOM mantech five year plan.

Superplastic Forming of Titanium

Titanium can be formed at elevated temperatures (optimum temperature of 1700 F for Ti-6Al-4V) by exerting gas pressure on one side of the part. This is called superplastic forming. The process is being rapidly adapted to production applications and has great potential for use with airframe and engine parts. The unique characteristics of titanium and some of its alloys at elevated temperatures permit concurrent superplastic forming and diffusion bonding (SPF/DB). AVRADCOM will fund studies to investigate both superplastic forming alone and SPF/DB.

More Complex Shapes, Less Weight

There are many small detail parts on virtually all helicopter systems that are made from titanium alloys with relatively poor formability. Because the necessary shapes cannot be formed, complicated assembly operations and joining by riveting and spot welding are required. This means higher assembly costs and heavier parts. Adoption of superplastic forming could allow combination of many details into single parts, thus reducing material, tooling, and labor costs. In addition to the cost savings, superplastic forming would allow more complex part geometries and improved aircraft performance through reduced weight.

By combining superplastic forming with diffusion bonding, we could realize dramatic cost and weight savings for titanium sandwich structures and other parts adaptable to a single forming and joining operation. Candidate components on the AAH-64, for example, are the nacelle door assembly, the firewall assembly, the lead lag main rotor hub link assembly, and the tail rotor fork. Other candidate parts include the engine access panel on the BHT Model 212 and engine case components and compressor blades for the T700 engine.

Less Maintenance A Bonus

Cost savings up to 70 percent and weight savings as high as 40 percent have been estimated for SPF/DB titanium parts. Estimated costs for SPF/DB structures are competitive with conventional aluminum structures in applicable areas. Reduced weight and lower maintenance for airframe structures should provide life-cycle cost reductions of about $2.8 million for the ten year life of a 560 ship AAH fleet. If the process were applied to the AAH firewall assembly, savings of $750,000 and weight reductions of 10.6 lb/part could result. On T700 engine case components, savings for the 560 helicopter fleet could amount to $8.4 million. Weight reductions would be as much as 20 lb per engine.

Increased Producibility of Phased Array Antennas

Phased array antennas typically are very expensive when compared with other antenna designs. As a result, mechanically scanned antennas have been preferred for Army airborne applications. This restricts the requirements that an airborne radar can satisfy due to the slower scan speed of conventional mechanical antennas.

A major cost contributor in fabricating a phased array antenna is the multitude of components necessary to fabricate such an antenna. By integrating the antenna functions on a modular subarray basis, significant cost reductions can be gained and producibility of the antenna improved. An electronics module approach to phased array antenna design results in a rather compact antenna design and reduces the total number of required array interfaces, both electrical and mechanical, while improving reliability and maintainability.

Existing electronics module designs (which include phase shifter, control logic, and drive circuitry) are costly to manufacture. Through the use of hybrid integration techniques in the fabrication of these modules and automatic production line testing methods, a significant unit cost reduction can be realized. Such a reduction will make array antennas more attractive for future use.

The technology derived from this mantech project will be applicable to the Stand Off Target Acquisition System (SOTAS) and the Mini Remotely Piloted Vehicle (RPV).

Fabrication of 4340 ESR Steel

Electrolytic slag remelt (ESR) 4340 steel is a relatively new material with good ballistic toughness used on various drive, rotor, and subsystem components of Army helicopters. Some fifty-eight components on the AAH-64 are made of ESR 4340. However, present methods of machining the material are very slow in comparison with machining of other 4340 steels, especially in the heat treated condition. AVRADCOM will fund research to develop improved machining methods for ESR 4340 by optimizing

- Feeds and speeds
- Cutter materials and geometry
- Material condition, i.e., heat treat, anneal, etc.
- Balance or "crossover" for normal machining and grinding for a given specified tolerance and surface finish.

It is anticipated that machining time can be reduced 50 percent through improved methods while improving surface finish and dimensional tolerance and extending cutter life.

High Strength, Low Cost Titanium Castings

By using integral compressor wheels (called blisks or impellers) in high performance gas turbine engines, designers are achieving significant weight reduction and reduced

leakage. These titanium impellers are presently forged and machined, resulting in considerable waste (starting material to finished part weight ratios as high as 8 to 1) and time consuming machining. On the other hand, investment casting has a near net shape capability and has shown promise with titanium impellers in preliminary feasibility studies. Therefore, AVRADCOM is funding research to develop the process by optimizing critical processing factors and establishing both producibility and reproducibility characteristics.

Machining Time Saved

The process being pursued involves casting slightly oversized parts to make sure that critical airfoil regions are filled. The casting step is followed by hot isostatic pressing to ensure total densification and is followed by chemical milling to obtain the required dimensions. Minimum savings of $6.25 million on the GMA 500 engine alone have been projected. In addition, lead times for the impellers will be reduced by elimination of time consuming machining operations. The technology developed will be applicable as well to other engine designs and to other components, such as compressor blades and fan bladed disks.

The main rotor hub presents a similar problem which also can be approached by combining casting and hot isostatic pressing. In this case, savings of $4.8 million on the UTTAS helicopter are foreseen.

Powder Metallurgy of Hubs and Disks

Rotor hub assemblies forged from aluminum alloys 7075-T73 and 2014-T6 provide limited notch fatigue endurance; as a result, their service life is much shorter than that of the balance of the structure. Replacement costs for these parts in terms of labor, material, and aircraft downtime are very high. To overcome this problem, AVRADCOM has funded work which is presently investigating aluminum powder metallurgy materials possessing fatigue strengths up to 80 percent higher than 7075 -T73; fabrication techniques will be developed to produce forgings. The material and techniques developed should be useful in the manufacture of all current and future helicopter rotor hub assemblies, as well as other fatigue critical rotating components. Components costs may be higher, but the reduction of life cycle costs will result in an estimated $8.76 million savings for a fleet of 600 aircraft.

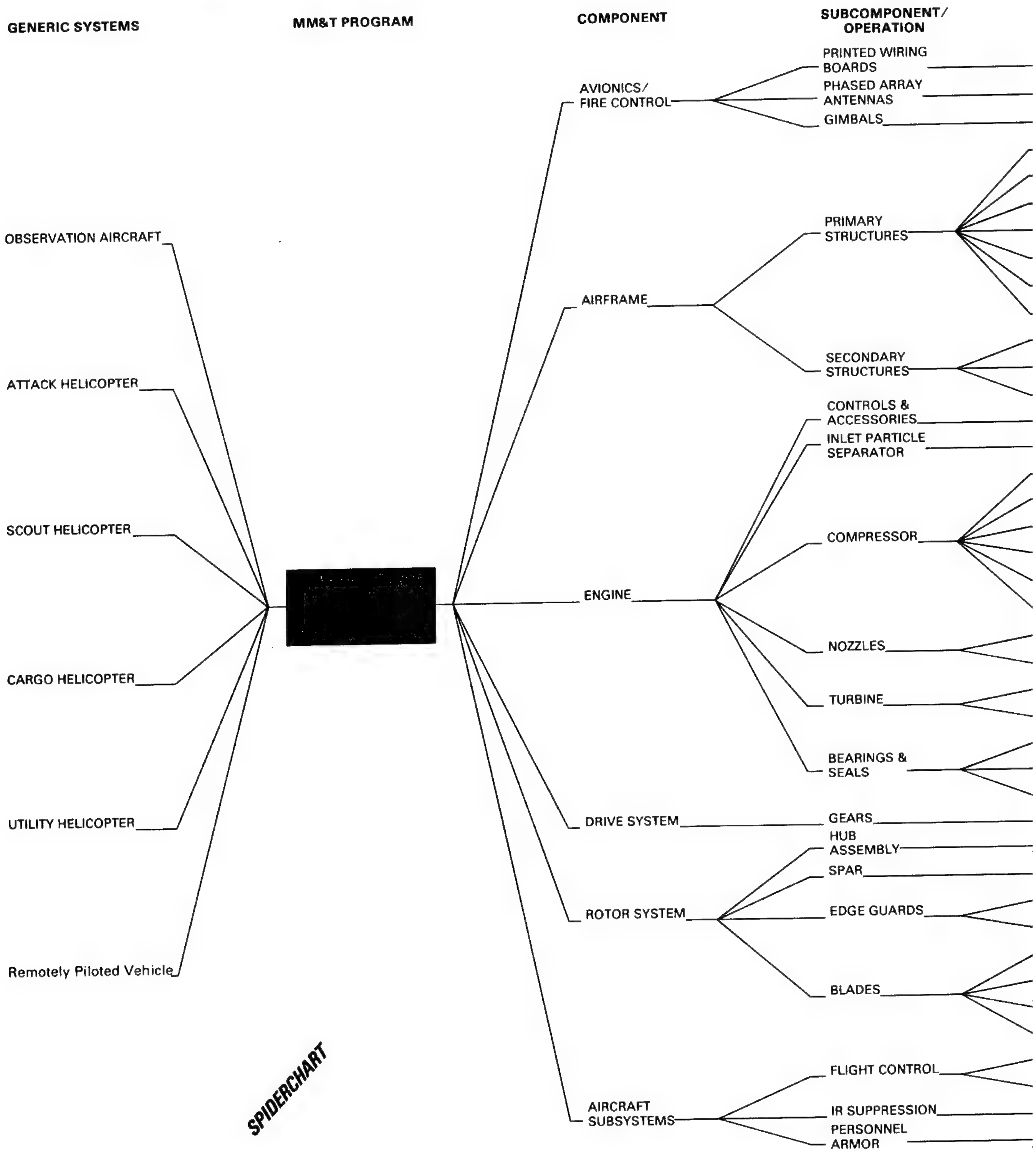
Savings of Material Dramatic

In a similar program, the use of powder metallurgy techniques for manufacturing superalloy turbine disks will be investigated. The Production Engineering Measures review board during their January 3-6, 1978 meeting recognized the need to improve powder cleanliness. Reducing the level of nonmetallic inclusions and thermally induced porosity will increase the yield of useful powder from the powder manufacturing processes and will permit higher design strength limits for many alloys. Present forged components utilize only 25 to 30 percent of the starting material, so tremendous savings in material costs are possible. Hot isostatic compaction of nickel alloy powder will provide savings in both material and machining time. To overcome these problems, the Army and Air Force are pursuing a joint effort to improve superalloy powder quality for use in aircraft engines. The process will have potential application to all gas turbine engines, with savings greater than 15 percent per engine estimated.

Conference Forum A Plus

Those are the major technology areas identified during the conference that AVRADCOM selected for immediate action. Achievement of the cost reduction goals in these areas alone certainly would justify having held the conference. However, as noted, the results have also been instrumental in shaping much of the rest of AVRADCOM's immediate MM&T program as well as its five year investment plan. In addition to these direct and measurable impacts, the conference provided an excellent forum for exchange of ideas between the Army and contractors and also between contractors themselves. Overall, the conference served as a key factor in advancing the AVRADCOM MM&T effort.

MM&T PROGRAM: U.S. ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND



	MM&T GOALS													TECHNOLOGY AREAS												
	Reduce Manufacturing Unit Cost	Reduce Facility/Capital Investment	Reduce Critical Resource Consumption	Required for Technical Data Package	Improve Reliability	Improve Producibility	Validate Prototype Equipment	Facilitate Quantity Production	Solve Production Obstacle	Reduce Life Cycle Costs	Improve Maintainability	Improve Survivability	Improve Performance	Energy Consumption	Materials Handling	Process Instrumentation	CAD/CAM	Automated Manufacture	Net Shape	Electronics Fabrication	Testing	Materials Processing	Electronics Testing	Metal Removal	Composite Fabrication	Joining
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In the Forefront of Technology

Highlights of Major Achievements

Articles describing new techniques in manufacturing developed by the Aviation Research and Development Command are among those drawing the highest response from readers of past issues of the Army ManTech Journal. In this issue of the Journal, interest will be especially keen in the areas of bonding and composites technology. A striking achievement in ultrasonic bonding is the topic of one of these articles on page 11, and a remarkable new tool for laying up plastics components is the topic of another article on page 15. Other highlights covered in the section discussing AVRADCOM achievements point to practical savings thru value engineering, increased reliability and extended life cycles for helicopter windshields, and a more efficient way of fabricating gas turbine engine compressor blades. Topics on extending the life of rotor blades, the advantages of precision forging of gears, and savings available thru diffusion bonding round out this presentation of some of AVRADCOM's most outstanding achievements in manufacturing technology. A section of brief status reports follows these highlight articles, but a lack of space for briefs about the many ongoing projects being worked on by this dynamic command makes it necessary to continue them in the next issue of the ManTech Journal. We believe our readers will find much useful and timely information in this issue of the magazine.

Ultrasonic Bonding Arrives

75% Cost Savings Seen

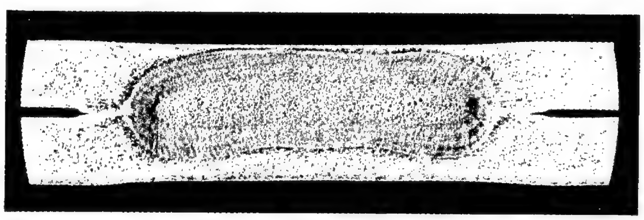
MS. JANET DEVINE is the Vice President of R&D for Sonobond Corporation. At Sonobond, she has supervised and conducted programs relating to the understanding of ultrasonics and its applications in metal processing—such as machining, drilling, forming, welding, and related ancillary processes. She is responsible for developing acoustical theory and reduction to practice of new concepts utilizing ultrasonic technology. She was placed in charge of all engineering activities including the experimental and production design of ultrasonic equipment for varied metalworking applications and was subsequently named Vice President, Research and Development. Her prior experience in the aerospace industry was in the United Kingdom, where she was associated with fluid dynamics research in the Ramjet Development Department of British Aircraft Company, Ltd. (formerly Bristol-Siddeley). Ms. Devine holds several patents and has published technical papers reporting the company's ultrasonic developments, including one on "The Development of a Torsional Mode Ultrasonic Beam Lead Bonder," which she presented to the Electronic Components Conference of the Institute of Electrical and Electronic Engineers. Another paper was on "Ultrasonic Welding (Solid State Bonding) of Aircraft Structures, Fact or Fancy", which she coauthored for The American Helicopter Society and The Ultrasonic Industries Association. She is a member of the Acoustical Society of America and the American Defense Preparedness Association.

ROBERT G. VOLLMER, Chief, Production Technology Branch, Army Aviation Research and Development Command (AVRADCOM), graduated from Washington University (1959), St. Louis, Missouri with a B.S. in Industrial Engineering. Subsequently, he has attended numerous government and industry schools, workshops, seminars, and courses on manufacturing technology and engineering management, as well as satisfied a portion of the graduate requirements for the MBA Degree at Chicago University. He worked in the Aerospace Industry (McDonnell Douglas and Boeing) for five years, and for the past 11 years he has specialized in Rotary Wing Aircraft Manufacturing Technology. Mr. Vollmer directs the AVRADCOM Mantech and Value Engineering Programs. Mr. Vollmer was largely responsible for the success of the AVRADCOM Mantech Symposium held in November 1977, which evaluated over 340 proposed projects. He is a member of the Committee to Review Sonic Welding Standards for the American Welding Society Handbook, member of the Red River Engineering Intern Training Center Curriculum Review Panel, member of the Tri-Service Manufacturing Technology Advisory Group (MTAG) Composite Committee, member, Army Aviation Association of America, Inc. (AAAA), is the AVRADCOM representative to DARCOM on Numerically Controlled Computer Aided Manufacturing NC/CAM, and is the Chairman, Production and Product Assurance Committee for the American Helicopter Society (AHS).

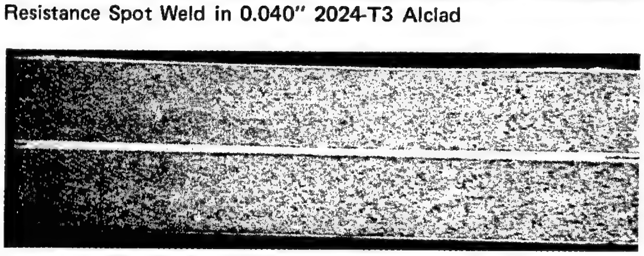
Ultrasonic bonding is a process whose time has come!—this is the feeling at AVRADCOM, at any rate. Efforts there appear to be having an impact on more widespread use of this generally neglected process in the fabrication of aircraft structures.

Results of recent AVRADCOM funded manufacturing technology studies at Sonobond Corporation and Hughes Helicopter Division demonstrate potential labor savings of about 75 percent for door assemblies fabricated by ultrasonic rather than adhesive bonding. Other studies have demonstrated sizeable cost reductions when ultrasonic bonding is compared with riveting and resistance welding. This emerging process also offers greatly reduced energy costs, and its solid state characteristics provide some significant advantages in other areas when compared with other joining processes (see Figure 1).

With the impetus supplied by AVRADCOM's careful research and support of the process, several aircraft companies are looking closely at possible ultrasonic bonding applications. In addition, the process has broad potential application in other industries once its advantages are recognized.



Resistance Spot Weld in 0.040" 2024-T3 Alclad



Ultrasonic Spot Bond in 0.050" 2024-T3 Alclad

Figure 1

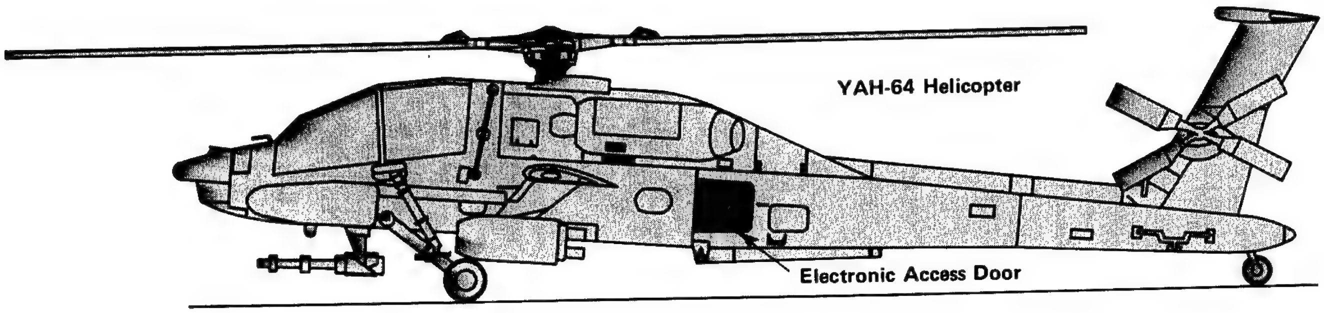


Figure 2

Access Door Costs Reduced Sharply

Sonobond and Hughes recently completed a demonstration study on an access door for the YAH-64 Advanced Attack Helicopter (see Figure 2). Adhesive bonding of this door takes about 2.7 hours assembly time, compared with 40 minutes for ultrasonic bonding. This translates to labor costs of $68 vs $17, a 75 percent cost reduction. Total savings for a run of 535 aircraft, each requiring six doors, would amount to over $160,000. In addition, the energy requirements would drop from 387 Kwhr per door for adhesive bonding to only 0.14 Kwhr for ultrasonic bonding, a cost reduction from $19.35 to $0.008 per door.

During this same study, it was determined that a single ultrasonically bonded joint costs approximately 0.1 cent. By comparison, the Drivmatic riveting system ideally costs 1.4 cents per rivet joint with the machine operating at 18 rivets per minute. Since skilled operators in the aerospace industry operate the Drivmatic at approximately 7.2 rivets per minute, a more realistic cost is 3.5 cents per rivet joint. In either case, ultrasonic bonding provides a dramatic cost reduction.

Further cost and weight savings are achieved by reducing the edge distance normally required for riveted structures. The material and weight savings after redesign of the door to adapt it to the ultrasonic process are approximately 40 percent.

Energy Conservation A Factor

We have already seen the sharp reduction in energy costs when ultrasonic bonding is compared with adhesive bonding. Aerospace contractors processing aluminum sheet or foil materials by resistance spot welding can also expect significant reduction in electrical energy requirements if they adopt ultrasonic bonding techniques. Aluminum ultrasonic bonds are made with high nugget quality at low temperature without joule heating. There is no molten interface and, therefore, energy requirements are greatly reduced. Also, because very high currents are not required, excessive IR losses in transformers, electrodes, and associated conductors do not occur. Hence, electrical efficiency of the bonding system increases dramatically.

Demonstration tests on the access doors (Figure 3) have shown that 0.040 inch thick aluminum can be ultrasonically bonded with a line input power of 8 kva and a weld burst of about 1 second (consuming about 8000 joules of energy). Direct current resistance spot welding of the same aluminum alloys requires over 800 kva line input power for 0.1 second, which corresponds to 80,000 joules of energy. It would take ten ultrasonic spot welders to consume the same energy. The results have consistently demonstrated energy savings per spot bond up to 90 percent (see Figure 4). Additional energy savings result because only about one half as many ultrasonic bonds as spot welds are required.

Great Potential For Aerospace Industry

Ultrasonic bonding is particularly appropriate for use with the reinforced metallic composites now finding widespread use in aircraft structures. The solid state joint does not break reinforcing fibers as do mechanical fasteners.

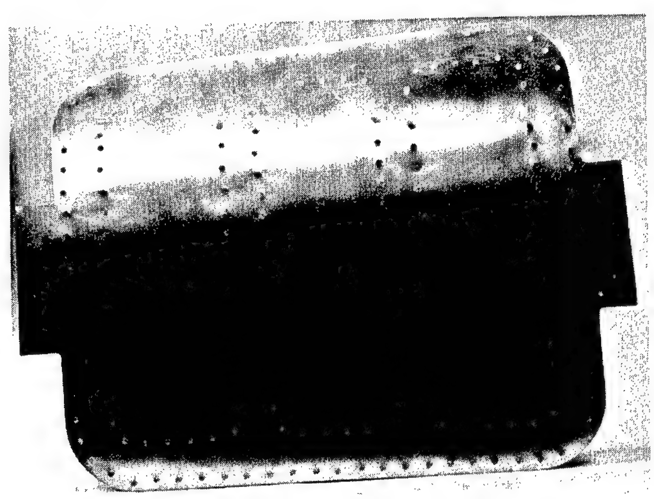


Figure 3

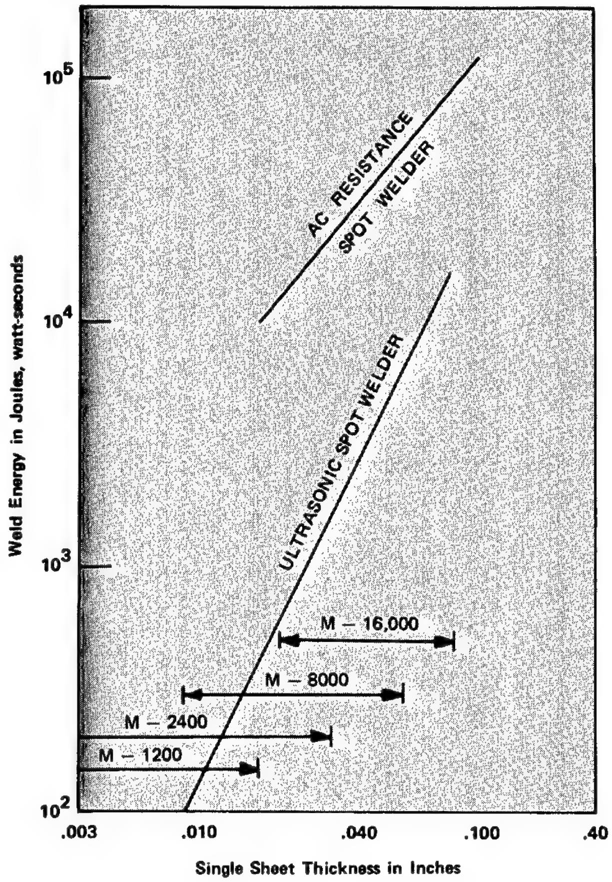


Figure 4

Because the process is adaptable to new alloys and combinations of diverse materials, it provides a valuable tool for the aerospace designer. He can use significantly new design philosophies, structural configurations, and alloys, and he can take full advantage of the composites available.

In addition, the use of ultrasonic bonding in processes other than bonding—e.g., extrusion, pultrusion, and machining—can in combination provide a product superior to that which can be processed in any other way. For example, extruded metallic composites with reinforcement fibers uniaxially oriented and in intimate contact with the metallic matrix are ideally suited for ultrasonic bonds. Here, induced superplasticity creates a solid state bond between the workpieces and results in improved adherence of the metal matrix to the reinforcement fiber. NASA apparently plans to use ultrasonic bonding extensively in their work with reinforced metallic composites.

Many Look to Ultrasonics

With such demonstrated potential, Hughes is seeking Army approval to use ultrasonic bonding for fabricating the access doors on the YAH-64 in order to conserve time, weight, and energy. It is now probable that the airframe subcontractor, Teledyne-Ryan, will use ultrasonic bonding in production.

Other companies are looking closely at ultrasonic bonding—Rockwell International's B-1 Division used ultrasonic bonding techniques on prototype doors for the B-1 avionics bay. These composite doors required maximum possible electrical conductivity through the bonded joint as protection against lightning strikes. The door was fitted with a titanium frame to which an aluminum screen was attached to establish electrical continuity. In the prototype, the titanium/aluminum joint was bonded by ultrasonic seam welding.

Hazard Eliminated

Fairchild Republic is exploring the use of ultrasonic bonding to replace fasteners in the A-10 airplane. Some change is needed for reasons of safety. When these aircraft experience projectile damage, the mechanical fasteners can become miniature missiles, further endangering crew members. Fairchild will probably acquire ultrasonic equipment for its laboratory to further explore use of the process for new and cost effective improvements to the A-10.

Grumman Aerospace is exploring the potential of ultrasonic bonding to assemble platforms in space. In addition, Grumman is investigating the possibility of using the process for the repair of high value components on new weapons systems. Lockheed Missiles and Space Division also is exploring cost effective uses of the process in the assembly of new weapons systems.

Commercial Applications Foreseen

Ultrasonic joining offers obvious advantages to civilian industry as well. For automotive manufacturers caught between the requirement of energy conservation(i.e., lightweight structure with attendant low gas consumption) and a safety conscious consumer, the benefits are highly significant. The ultrasonic process is eminently suitable for bonding aluminum panels and electrical components such as starter armatures, windshield wiper armatures, brush plates, and harnesses (Figures 5 and 6).

The electronics industry requires strong bonds with low ohmic values for many products. Ultrasonic bonding is an obvious answer. Small motor manufacturers, both in the United States and overseas are exploring its use, especially for hand tools.

Not A New Process

The process discussed here is not really new. The application of ultrasonic energy to joining metals has been well known for many years. However, the full potential for this simple and cost effective process has never been realized because the mechanics of the process are not as

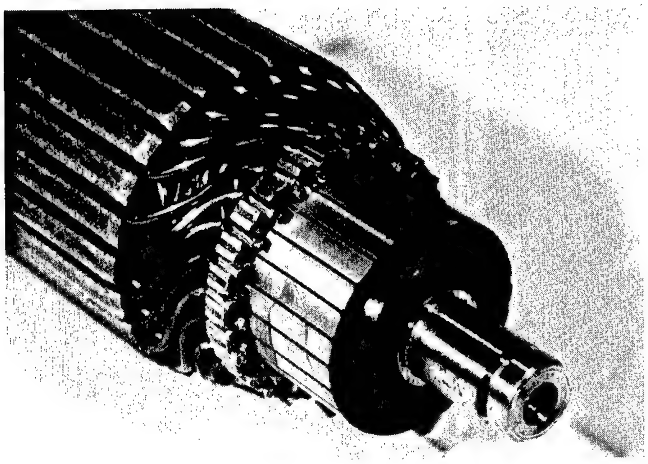


Figure 5

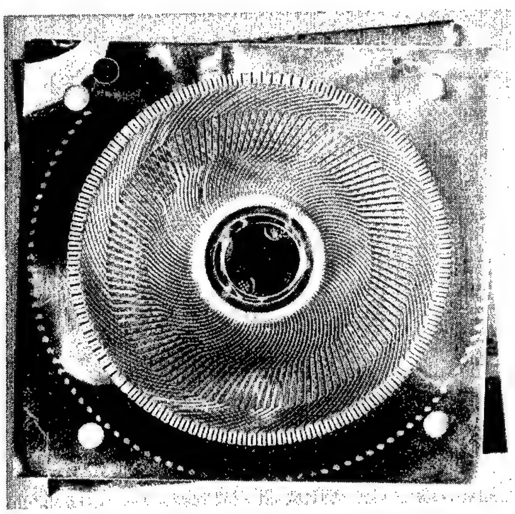


Figure 6

straightforward as those of other welding processes and are often confusing to potential users.

Ultrasonic bonding is a solid state metallurgical joining technique. The ultrasonic energy disrupts surface films and oxides. This promotes diffusion of atoms across the interface and plastic flow between the contacting surfaces that develop. There is no melting of the metals.

Ultrasonic bonding can be used with or without an adhesive layer at the interface. An adhesive additive increases the effective bonding area without using an excessive number of ultrasonic bonds. When an adhesive is used, the ultrasonic energy partially disrupts the adhesive film allowing direct metal contact. In the areas where metal contact does not occur, ultrasonic energy apparently accelerates adhesive curing action. The resulting joint is stronger than those obtained by either ultrasonic or adhesive joining techniques used separately.

Serious Application Effort Needed

There are reasons why ultrasonic bonding has not won widespread acceptance as a production process earlier. Investigators have usually concentrated on small scale laboratory feasibility studies without considering actual manufacturing problems. They have not attempted to convert the technology into specific hardware that would allow realistic cost comparisons. The few production engineers that do look toward ultrasonic bonding want ready made solutions to their problems. When they don't find them, they drop the process, assuming the solutions are too costly or too time consuming to pursue. As a result, the actual or potential benefits of ultrasonic bonding have been slow to gain acceptance or even recognition.

AVRADCOM has been a leading advocate of the technology for some time, however. In the early seventies, AVRADCOM and Sonobond sought to identify areas for implementation in the aerospace industry.

From this early work with Sonobond, AVRADCOM recognized that a process specification could stimulate greater use of ultrasonic bonding for more cost effective production of Army aircraft. Sonobond was asked to help generate such a specification. They in turn enlisted the support of Hughes to help identify a specific area of implementation. Sonobond and Hughes agreed that ultrasonic bonding of an access door would provide a suitable demonstration. The resulting process specification could form the basis of a military specification for ultrasonic bonding of other secondary structures for military aircraft.

The results of that effort, as discussed here, have established the potential for substantial cost savings. Future use of the process now depends heavily upon its acceptance by industry.

Hughes has conducted extensive tests on the ultrasonically bonded door, resulting in an industrial process specification; Hughes also has initiated action to secure the Army's approval for implementation of ultrasonic bonding of the door. Development of the process specification should certainly contribute to wider acceptance; and, as we have seen, interest in the process is picking up.

Portable Units Next Objective

Upon successful completion of the project to ultrasonically bond secondary structures, AVRADCOM will initiate a follow-on project to apply ultrasonic bonding to primary load bearing structures. This additional investigative effort has been assigned to the Applied Technology Laboratory, Ft. Eustis, Virginia, to monitor. During that project, the use of adhesives in conjunction with ultrasonic bonding will also be investigated. AVRADCOM will seek to perfect methods for making portable ultrasonic bonding machines.

Energy, Labor
Costs Cut Sharply

Composites Tooling Speeds Fabrication

DR. BERNARD M. HALPIN, JR. is currently a group leader in the Composites Development Division of the Army Materials and Mechanics Research Center, with an overview of the processing and prototyping of organic materials in the Organic Materials Laboratory. He has been active in the field of composites since 1971, having started at AMMRC in 1969 as a synthetic organic chemist. He holds a B.S. in Chemistry from Merrimack College and a Ph.D. in Organic Chemistry from Boston College.

EDITOR'S NOTE: Gerald A. Gorline, Manager of AVRADCOM's Manufacturing Technology Program for the past 12 years, participated as coauthor of this article on composites tooling. His complete biographical sketch is on Page 28 as author of the article on clad rotor blades.

Through Army funded research, Hughes Helicopter has perfected new low cost tooling for composite fabrication. Calling it hot layup tooling, Hughes has adapted the process to fabrication of an aft engine fairing for the OH-6A helicopter and demonstrated cost savings of $87 per part, primarily in labor and energy costs. In addition, redesign of the fairing to accommodate the tooling and a materials switch from E-glass to Kevlar-49® resulted in a $376 labor savings per part.

Long Production Life A Feature

Beyond the cost savings, hot layup tooling offers a relatively long production life and a lead time identical to plastic tooling and half that of comparable cast aluminum tools. The process has now been adopted for production use on the Hughes Model 500, the commercial version of the OH-6A. It also may be used on the Advanced Attack Helicopter (AAH). Investigation of additional applications using filament winding mandrels or curing molds, matched multiple die tooling, and larger part molds has been recommended.

The Hughes development effort was sponsored by an AVRADCOM (then AVSCOM) MMT Program and the contracting effort was monitored by AMMRC. The hot layup tool, originally developed for high energy rate forming of metal parts, is fabricated from wire reinforced concrete with a nickel liner. Adoption to composite fabrication required the inclusion of integral heating and cooling elements. In conjunction with the tooling study, Hughes also investigated the use of Kevlar-49® as an alternate material.

Part Redesign Required

The aft engine fairing was selected for fabrication because:

- It was of a reasonable size—35x21x15 inches and weight of 5 pounds.
- Its location permitted evaluation of the effect of a Kevlar-49® component on the flight of the aircraft.
- Its second degree contours permitted evaluation of how well the hot layup tool could reproduce surfaces and contours.

The standard aft inlet fairing, fabricated from E-glass/polyester, included twenty-eight stiffening blocks of polyurethane foam molded between the inner and outer skins—it required three curing cycles.

The initial step in the development of new tooling was redesign of the part, which involved two major elements. First, replacement of the urethane blocks with Nomex® honeycomb—this allowed better heat transfer from the tooling to the inner skin. Second, simplification of the design by reducing the number of parts—this decreased manufacturing costs.

The final fairing design is shown in Figure 1. The inner and outer skins are 181 style Kevlar-49® cloth impregnated with epoxy resin; the Nomex® cure is 0.625 inch thick.

Mold Design Variable

The hot layup tool is basically a male or female, low cost, self heating and cooling tool in which composite materials are laid up and cured. In a high production rate version it is a nickel faced, wire reinforced concrete tool with integral heating/cooling pipes; in a low production rate version the nickel facing would be replaced with an epoxy facing.

There is also the closed die configuration (Figure 2) for the hot layup tool in which matched nickel faced male and female dies are used together to effectively serve as an autoclave. But an actual autoclave with its heating and pressurizing systems is not required.

The Hughes hot layup tool is comprised of a female mold designed to form the outer contour of the inlet fairing. Its cavity is lined with an electrodeposited nickel skin 0.10 inch thick. Copper tubing behind the lining provides for heating and cooling (see Figure 3).

Nine Units Produced

The Hughes program included fabrication of nine parts to evaluate the tooling. Fairing fabrication involved eleven steps, as shown in Figure 4. First, Hughes cut the Nomex® honeycomb and dinked the uncured prepreg Kevlar-49® outer skin to size. The outer skin, honeycomb, and sheet metal parts were then loaded to the tool and cured. (During this program, curing was done at 250 F for 70 minutes.) Figure 5 shows relative cooling times for HLT versus oven curing.

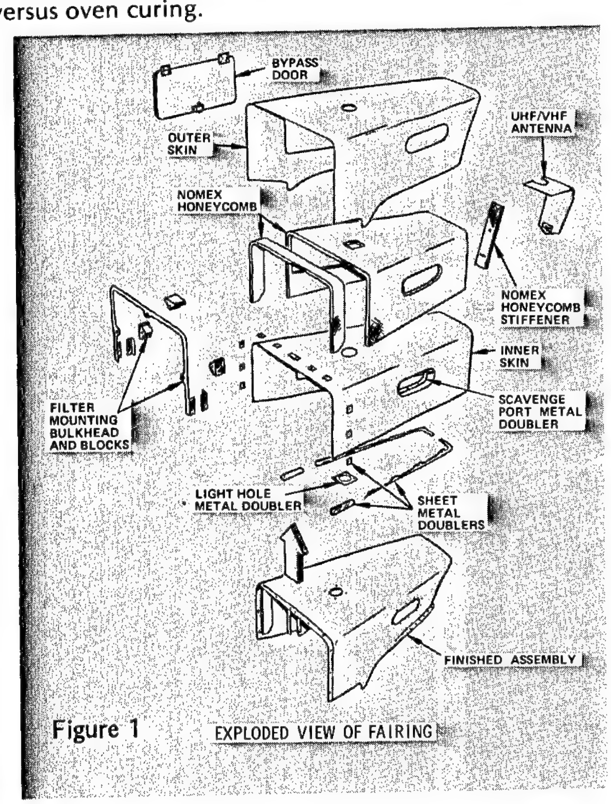


Figure 1 EXPLODED VIEW OF FAIRING

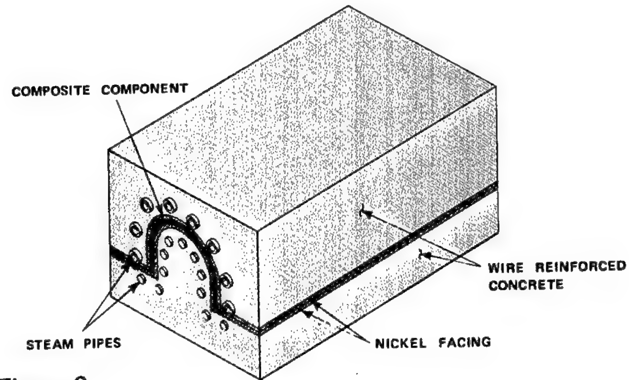
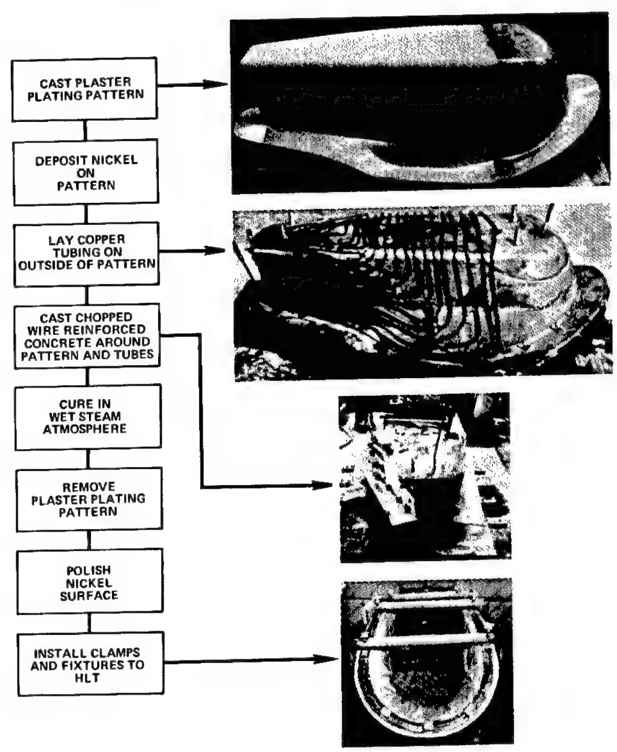


Figure 2

After curing, the filter bulkhead and attach blocks were bonded into the assembly. Tubes and conduits were then set into the honeycomb and the inner skin was laid over the part before a final cure. The fairing was removed from the tool for finish machining and the addition of the air bypass door, controls, anchor nuts, and inserts.

Material Cost Reduction Needed

This entire operation required 10.8 hours compared with an average of 33.19 hours per fairing during actual



FABRICATION SEQUENCE FOR HLT

Figure 3

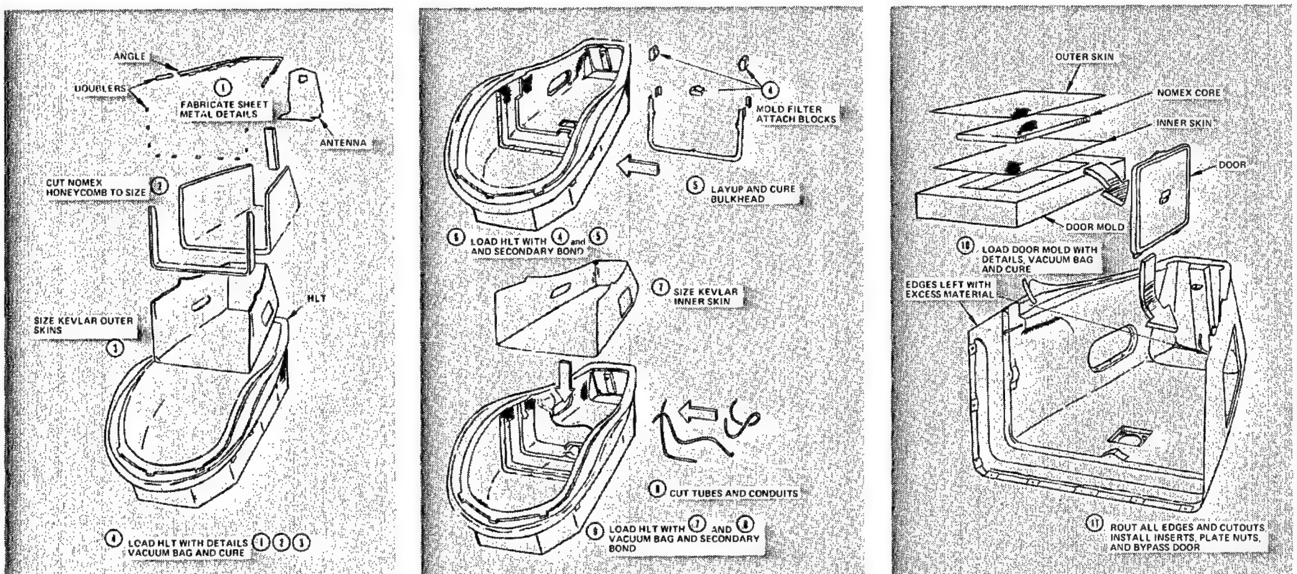


Figure 4

production in 1974—a savings of 22.39 man-hours per fairing over the foam block stiffened structure. Future plans call for development of a single step cure which should save even more time.

Cost savings attributable to the hot layup tooling are summarized in Table 1. The table also indicates savings attributable to the redesign. The major areas of savings are labor and heat energy. The hot layup tooling uses heat energy directly and only when needed. Thus, it is more thermodynamically efficient than oven curing, therefore much less costly.

	Oven Cure/Plastic Tool		
	Old Design	Redesign	HLT
Facility and Maintenance	$ 4.30	$ 4.30	$ 0.67
Energy	16.10	16.10	1.11
Mold Amortization	1.44	1.44	0.93
Labor at $20.00/hr	644.00	268.00	200.00
HLT Savings			87.00

Table 1

The use of Kevlar reduced the weight of the fairing by 0.67 pounds. However, the material cost increased by $53 per fairing over fiberglass in the same configuration. This amounted to $79.10 per pound of weight saved. A more acceptable range would be $30 to $40 per pound of weight saved, which requires reduction in the cost of the Kevlar.

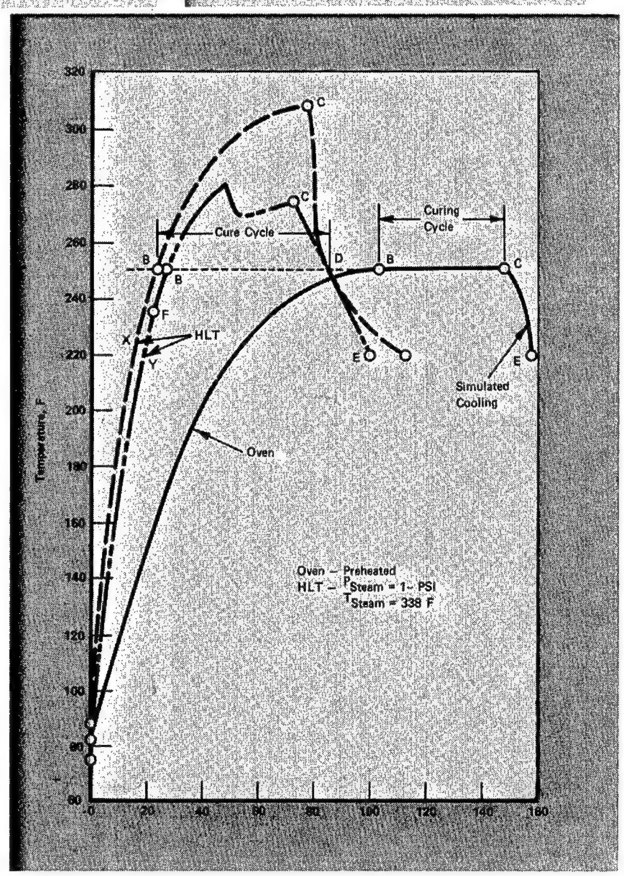


Figure 5

Copter Windshields Made Tougher

Special Coating Extends Life, Adds Safety

Whether flying in combat under heavy fire, moving logs out of the forest, or perhaps evacuating flood victims along a swollen river, a helicopter pilot relies on clear vision. A scratched up, unclear windshield is certainly no help. Nor does he want to worry about glass fragments flying around the cockpit if something hits that windshield—whether its a bullet, a rock, or a bird. Unfortunately, these are problems helicopter pilots have been faced with.

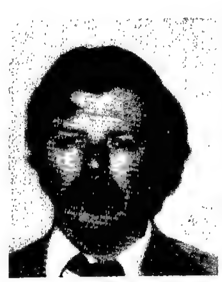
Now engineers at the Army's Materials and Mechanics Research Center (AMMRC), working closely with Goodyear Aerospace Corporation, have developed a coated polycarbonate windshield design that virtually eliminates such problems. With a hard, abrasion resistant coating called Abcite* on both its surfaces, this windshield design has demonstrated a service life of approximately 1200 hours—nearly four times the average of a typical acrylic windshield. At the same time, in ballistic impact tests the windshield has shown practically no spalling—none of that unwanted glass shooting about the cockpit. Thus, the new design offers a large savings through extended service life, and also much improved crew safety.

The Goodyear development effort was sponsored by an AVRADCOM MMT Program, and the contracting effort was monitored by AMMRC.

Transparency Loss Widely Experienced

The Army initiated the study leading to this development when combat reports indicated that the most prevalent problems with helicopter windshields were loss of transparency and spalling. The loss in transparency was attributed to scratching resulting from wiper blade action and dust blown about by prop wash. The standard acrylic windshields simply were not hard enough to withstand the abrasive conditions met in combat use, so frequent replacements were necessary.

At the same time, the impact of small arms projectiles caused severe cracking and spalling problems, endangering the safety of crew members. This problem was



JOHN R. PLUMER is an environmental scientist in the Composites Development Division, Organics Materials Laboratory, U.S. Army Materials and Mechanics Research Center, Watertown, Massachusetts. He attended the University of New Hampshire prior to joining AMMRC in 1971 as an active duty army officer. Mr. Plumer has been active in the areas of prototype composite design and battle damage simulations. He has served as a principle investigator on a number of projects directed at the development of plastic composite transparent armor for aircraft and has published several technical reports in this area.

*Trademark, Corning Glass Works, Corning, N.Y.

even greater with laminated glass windshields than with the acrylic.

Many of these same conditions (minus the hostile small arms fire, of course)—the blowing dust, sand, and rock; extended wiper use in heavy rains; birds—are faced in more normal helicopter operations. So the AMMRC development could have widespread application.

Three Configurations Tested

In initial testing at AMMRC, three experimental configurations were fabricated. A polycarbonate windshield material was used in each of these designs, employing either a hard surface coating, an acrylic cladding, or a thin glass cladding. A variety of polycarbonates, hard coatings, acrylics, and glass cladding materials were evaluated, as shown in Table 1.

From these initial studies, two polycarbonate designs were selected for flight testing and additional impact testing. One had a thin glass cladding called Chemcor on the outside surface, with an Abcite coating on the inside. The other had an Abcite coating on both surfaces. Laboratory tests indicated that both designs would improve abrasion resistance and that this greater toughness would virtually eliminate spalling problems of the standard acrylic windshields.

For the additional tests, an acrylic windshield was used as a standard. Figure 1 shows the configurations of the three test items. Testing on full sized parts included actual flight testing to determine abrasion resistance, as well as both bird and ballistic impact tests under simulated flight conditions.

Glass Cladding Most Abrasion Resistant

The flight tests demonstrated the validity of both concepts for improving abrasion resistance. The glass clad item showed the highest resistance of the three—it was virtually free of scratches or abrasions at the conclusion of flight tests. The Abcite coated windshield also was far superior to the standard acrylic item—a superiority maintained until an appreciable amount of the coating wore off (after about 900 flight hours) due to environmental effects. Serviceability was extended to about 1200 flight hours. The acrylic windshield developed appreciable surface wear (haze) by 350 flight hours.

An interesting observation was made by one researcher who reported that haze increased rapidly with the development of surface abrasion up to a certain point, above which haze decreased temporarily (see Figure 2). The abrasive action apparently polishes out previous scratches at about 40% transmission.

Coating	Materials	Source
Uncoated	Polycarbonate, Lexan, SL-2000-111	General Electric Co.
	Polycarbonate, Lexan 9030-112	General Electric Co.
	Polycarbonate, Merlon M50U	Mobay Chemical Co.
	Polycarbonate	Rowland Products, Inc.
	Acrylic, as-cast, Mil-P-5425	Rohm Haas
	Acrylic, stretched, Mil-P-25690	Rohm Haas
	Urethane 574	Goodyear Aerospace
	Acrylic, as-cast	Section UH-1 Windshield (used, unserviceable)
	Acrylic, as-cast	Section UH-1 Door Window (used, unserviceable)
Abcite	Acrylic, Mil-P-5425	DuPont
Abcite	Polycarbonate	DuPont
Abcite (GACA 701)	Urethane GAC 574	Goodyear Aerospace
Abcite (GACA 701)	Polycarbonate	Goodyear Aerospace
Armor Clad	Acrylic Mil-P-5425	Symbolic Displays
#100-35	Polycarbonate	Astro Research Co.
ESB	Polycarbonate	ESB Corp.
MR-4000	Lexan 9030-112	General Electric Co.
Mobay	Merlon M50U	Mobay Chemical Co.
650 type Glass Resin	Acrylic, as-cast	Owens-Illinois
SS-6426 ARC	Acrylic, Mil-P-25690	Swedlow Inc.
SS-6432	Polycarbonate	Swedlow Inc.
No. 311	Acrylic, as-cast	Sierracin Corp.
Texstar	Polycarbonate	Sierracin Corp.
0401 type	Glass	Corning Glass Co.

Table 1

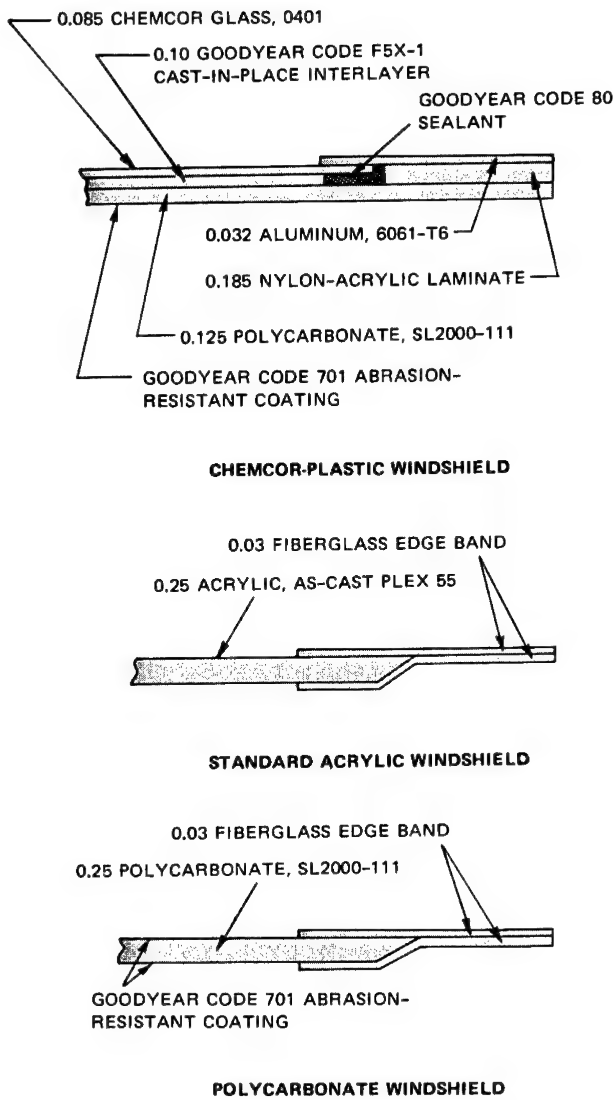


Figure 1

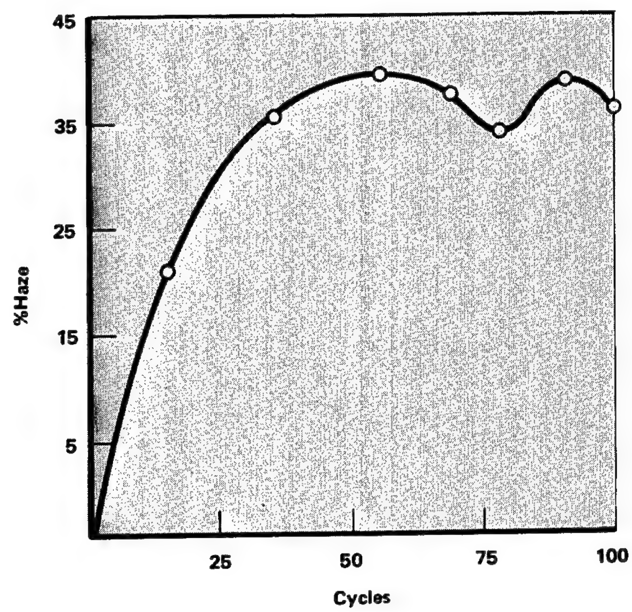


Figure 2

Hard Coating Best Ballistic Shield

In ballistic impact tests, very few fragments were dispersed behind the Abcite coated windshields and damage to the windshields was minimal. There was no cracking with the typical ballistic penetration and the resulting hole partially closed to about 1/8 inch diameter. A few small particles emerged at the back, but none of these reached the "witness" sheet, which was placed 6 inches behind the target. This would indicate no danger to the pilot.

The standard acrylic windshield, on the other hand, fractured at the point of impact, producing widely dispersed, sharp edged fragments of varying size. Dispersion was so wide that many particles missed the witness sheet. However, none of these particles perforated the witness sheet, which would have indicated potential lethality.

The glass clad windshield did generate potentially lethal fragments, and the overall spalling characteristics of this windshield were the least desirable of the three.

Experimental Designs Superior

The two experimental windshields offered far greater protection against bird impact than did the standard acrylic windshield. In simulated tests, birds penetrated the acrylic windshield at both the maximum speed of the UH-1 helicopter (120 knots) and at its cruising speed (90 knots). In both cases, the windshield broke into large, sharp edged pieces that could endanger the crew.

Abcite coated windshields cracked when impacted by birds at top speed but there was no spalling and no penetration. The glass clad windshield withstood penetration, but there was some dispersal of fragments in the cabin area. Both experimental windshields probably would offer even better bird impact resistance if the windshield edge attachments were redesigned to withstand higher loads.

As a result of this program, AMMRC recommended the Abcite coated windshield configuration as a feasible—indeed, desirable—replacement part for helicopters operating in severe field or combat conditions. Use of this windshield will sharply reduce replacement costs, while providing improved aircrew protection.

Value Engineering Pays Off

Solid Savings Occur

ROY CROMWELL works for the Production Technology Branch, Army Aviation Research and Development Command. He has studied Civil and Sanitary Engineering at the University of Missouri during his 40 years as a practicing engineer. He has worked for the city government, federal government and industry. Since 1943 he has worked on the design and development, production, and procurement of ordinance for the Department of Defense. He has worked as a stress analyst and materials engineer on design and development, the world's largest wooden glider (CG-10) and the world's first fiberglass glider, for the Army & Navy Air Force; metal armament fire control systems for aircraft turrets for both Air Force and Navy; rocket launchers (ASROC, Terrier & Talos) for Navy and Pershing for the Army. He coordinated the conversion of prototype design drawings into production drawings on the CG10-Glider, the Terrier, and ASROC Launcher. He was an industrial engineer for the Munitions Branch of the Army's St. Louis Procurement Office, and also was their Chief Value Engineer and Chief of the Quality Development Research Information (QDRI) Board. The Department of Defense has patented some of Mr. Cromwell's designs for safety—restraining nuclear warhead missiles in the launcher until ready for release. As a Value Engineer for AVSCOM (now AVRADCOM) since 1966, Mr. Cromwell has made several Value Engineering studies that resulted in the reduction of life cycle costs. He is a member and Past President of the Society for American Value Engineers, Gateway Chapter, covering Missouri and Illinois.

Editor's Note: Mr. Cromwell retired from his position at AVRADCOM in August 1978, following 35 years of engineering work for the armed services.

JOHN D. BOUCHILLON, of the Production Technology Branch, Army Aviation Research and Development Command (AVRADCOM), graduated from Mississippi State University (1961), with a B.S. in Electrical Engineering. Subsequently, he has attended numerous government and industry schools, workshops, seminars, and courses on value engineering and engineering management. He has worked in the Aerospace Industry (AVSCOM and AVRADCOM) for 18 years, and for the past 11 years he has specialized in Rotary Wing Aircraft Value Engineering. Mr. Bouchillon directs the AVRADCOM Value Engineering Program. He is Past President and current member of the Gateway Chapter of the Society of American Value Engineers.

An important adjunct to the manufacturing technology effort at AVRADCOM is provided by value engineering. The road to substantial cost savings through value engineering can take some surprising and remarkable turns, AVRADCOM engineers have learned. Their achievements run the gamut from redesign of parts and testing of new combinations of components to overhaul or repair of aircraft parts as optimum avenues to follow. These studies address problems that arise during production and service and that also affect life cycle costs and performance—factors that determine value; they often have a direct impact on manufacturing technology. A value engineering study on a simple hinge pin, for example, resulted in better performance and savings of over $1.6 million.

The value engineer applies a particular set of techniques to evaluate different approaches to solving a problem. During the evaluation, he may consider manufacturing techniques, materials, part design, repair procedures, procurement, use factors—any phase in the life of a part that may be changed to reduce its cost and improve its performance.

A value engineering team of four to six members seems to get best results. The team follows five basic steps to analyze a problem in order to improve a part and reduce its life cycle costs:

- State the problem and objectives carefully and completely.
- Gather information that fully defines the problem.
- Analyze the information to determine causes of the problem.
- Apply creative thinking to generate ideas about ways to solve the problem.
- Apply judgemental thinking to evaluate the ideas and determine those that can be implemented most practically and most economically.

A quick look at a few specific value engineering projects at AVRADCOM over the past several years will illustrate the importance of value engineering studies to the manufacturing technology effort.

Coating Extends Ring Service Life

As a result of a value engineering study on the UH-1 rotor head, repair costs were reduced by about $750,000. The study arose because of the short service life of rotor head radius rings (Figure 1). Grooves worn in the seal area were causing oil leakage and consequent overhaul of the heads after an average of just 77 hours of flight time. Since the rotor head has a service life of 1100 hours, this leakage was causing excessive downtime as well as high costs.

Different coatings were evaluated for improved wear. After testing on an aircraft, AVRADCOM engineers found that flame plating with a tungsten carbide plus cobalt binder insured an 1100 hour service life. As a matter of fact, when the first rotor head equipped with the new rings was returned for overhaul after 1098 hours, the rings showed no signs of wear and were reinstalled.

As noted, direct savings due to reduced repair costs were estimated at nearly $750,000. There also were significant (but incalculable) savings related to decreasing the number of rotor heads needed in the supply system, in-

Figure 1

creased aircraft availability, decreased procurement of radius rings, and decreased wear on other rotor head parts due to reliable lubrication.

Hinge Pin Redesign Saves $1.6 Million

The redesign of a hinge pin for the CH-47 rotor blade more than tripled its service life (with rework) and resulted in an estimated $1.66 million savings over 3 years. These pins, together with two roller bearings, form a hinge that allows the rotor blades to rotate in the vertical plane. (There are two rotor blades, each containing three hinge pins, on an aircraft). During rotation, centrifugal load and lead lag forces cause the hinge to deflect, resulting in spalled bearing surfaces on the hinge pin. With the position of the hinge pin fixed, the spalling always occurs on the same side.

The hinge pin, as originally designed, had a life expectancy of 900 hours on the CH-47A and 450 hours on the CH-47A/C. This fell far short of the desired 3600 hour service life. Besides, the pins were scrapped whenever the rotor head was overhauled, regardless of the hours of life cycle remaining. With the pins costing $700 each, replacement costs were high.

After investigating various approaches to extending service life, AVRADCOM engineers concluded that modification of the pin to improve its bearing surface provided the best avenue. Changes in hinge pin material, in design of the bearing, and in the type of lubrication also were considered.

The modification was made by decreasing the pin diameter and placing an M-50 steel sleeve over it with an interference fit. The redesigned pin is shown in Figure 2. Tests showed that these pins have an expected service life of 1200 hours. The pins also can be repaired twice (by replacing the sleeve) before they are scrapped. Original cost of the redesigned pins is the same ($700), but they cost only $500 to repair. With the extended service life and reduced cost of repair vs. replacement, savings were estimated at $533,000 for the first year and at $562,000 for each of the next two years. First year costs included engineering and testing to validate the concept.

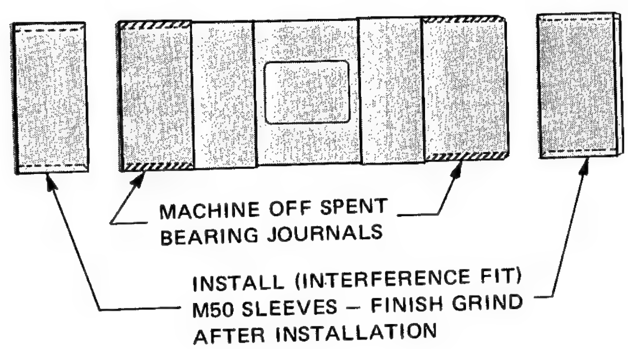


Figure 2

Improved Auxiliary Ramp Results

A careful study of the auxiliary ramp for the CH-47 helicopter resulted in a new ramp that was more rugged and less expensive. The new ramp, seen in Figure 3, costs only about $200, a savings of around $300.

The ramp is used for loading and unloading the aircraft and as a work platform for inspection or removal of the auxiliary power unit. The original ramp assembly was made of thin metal sheets braced with angles and filled with honeycomb core. It measured 18 inches wide by 37 inches long, including a hinged pad with a triangular cross section at one end to provide footing on soft ground. The replacement rate for the ramp was very high because of damage from wheels of loading vehicles dropping off the edge, and also because of breakage of the diagonal support braces when the ramp was used as a work platform. Another

problem was clogging of the hinges with sand and dirt, making proper adjustment of the ramp to accommodate vehicles of different width difficult. This led to much of the damage to ramp edges.

After evaluating several ideas, engineers at AVRADCOM redesigned the ramp. The new ramp is a hollow aluminum extrusion, with a bevel edge to replace the triangular, hinged pad, and detachable legs to replace the braces. It's 3 1/2 inches wider and 14 inches longer than the old ramp. With annual procurement estimated at about 1000 ramps, the new ramps resulted in a sizeable cost reduction and also proved to be more durable and practical.

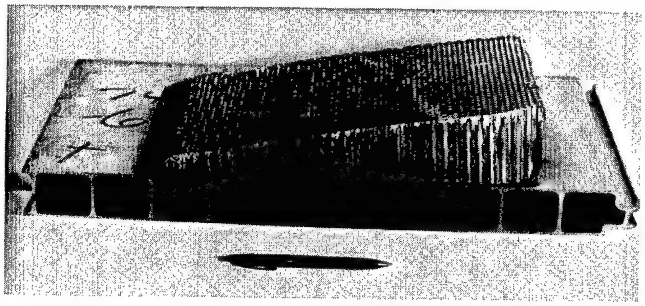


Figure 3

Repair Saves Nearly $50,000

Value engineering studies don't always result in new or redesigned parts. In the case of a map case and flight report holder for the OH-6, a study showed that optimum savings could be realized by repairing rather than replacing the item. The holder, shown in Figure 4, is located on the nose section of the aircraft next to the floor. About 120 are damaged and replaced each year. The holder looks very inexpensive, but because of its molded contour and support brackets needed to fit the contour of the nose section, it actually costs $467.25. Thus, the 120 holders being thrown away each year are worth $56,070.

As a result of a value engineering study, AVRADCOM engineers learned that the holders were scrapped primarily because of a worn out latch strap. The cost for repair of these cases is only about $35. The repair process for fiberglass was already in the manual and repair material was in stock. The solution became simply a matter of recoding the item from expendable to repairable at the field level. Analysis showed that the replacement rate would drop by about 90 percent when repairable items were no longer scrapped. Thus, each year about 108 holders can be repaired at a cost of $35 each rather than replaced at a cost of $467.25—an annual savings of $46,683.

In arriving at this solution, the team also considered replacing the case with other available but less expensive cases; eliminating the item; and replacing it with a mesh bag. All these ideas presented drawbacks to implementation from the standpoint of cost effectiveness or practicality.

Seatbelt Change Saves $144,000

By changing from a troop seatbelt (top of Figure 5) to the passenger seatbelt (bottom of Figure 5) on passenger seats in the UH-1A/C cargo compartment, AVRADCOM saved about $144,000 on a fleet of 4000 aircraft. This change came about through a value engineering study designed to evaluate life cycle costs of the seat belt.

The passenger belt was 44 percent lighter than the troop belt and made of less expensive material. Cost of the passenger belt is only $7.63, compared with $11.63 for the troop belt—a savings of $4 or $36 per aircraft. Furthermore, the passenger belt has a high production rate and short delivery time. In addition to the cost savings and reduced weight, the new belt fits small passengers better, adjusting to 6 inches less circumference.

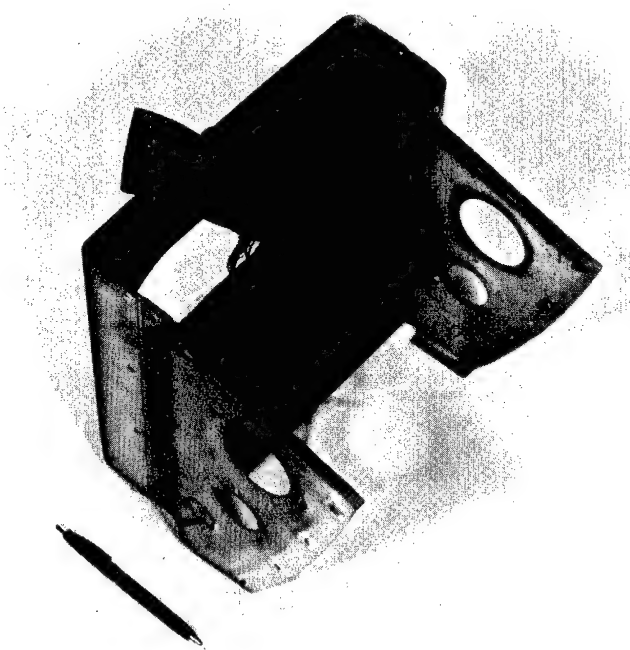


Figure 4

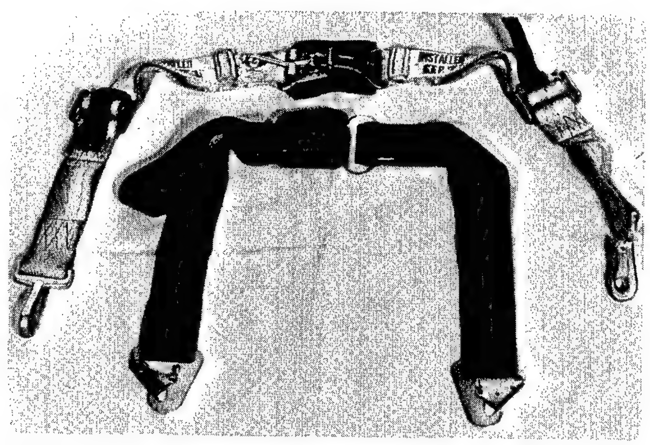
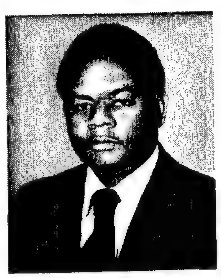


Figure 5

NC Equipment Spurs Blisk Manufacture

Full-Scale Production Slated



FREDRICK H. REED is a group leader in the Production Technology Branch, Development and Engineering Directorate, U.S. Army Aviation Research and Development Command, with responsibilities for Producibility Engineering and Planning (PEP), Military Adaptation of Commercial Items (MACI), and Manufacturing Technology. He is a graduate in Electrical Engineering of Howard University, Washington, D.C. (1969) and the DARCOM Intern Training Center in Industrial/Production Design Engineering (1971). Since joining the federal service, he has held various positions in the Army Aviation Production Base Support Program, including AVSCOM Facilities Coordinator and NC CAD/CAM Coordinator for AVRADCOM. Mr. Reed is a member of the Institute of Electrical and Electronic Engineers and the American Helicopter Society.

Through the use of computer directed numerical control equipment, General Electric has developed an automated process for the manufacture of blisks (an integrated blade and disk) and impellers for helicopter engine compressors. An AVRADCOM ManTech Program is now under way to implement this method into the manufacturing process for the T700 engine at a significant cost reduction.

New GE Facility Will Consolidate

An important advantage of a new General Electric facility at Hooksett, N.H., lies in performance of all operations in the blisk manufacturing process at a single location. These operations are now performed at five widely separated locations, resulting in high transportation and handling costs.

Development has proceeded in two stages—first, development of the process and equipment; then, the present implementation into a manufacturing facility geared to specific production schedules. The history of this development began in the mid-sixties.

Project Begun During Vietnam Conflict

In the mid-sixties, the Army initiated studies to define a new transport helicopter with advanced airframe and engine design. Based on the experience of hundreds of thousands of flying hours in Southeast Asian war zones, requirements were established for a tactical twin engine utility transport helicopter.

These requirements called for an engine in the 1500 shaft horsepower class. Compared with then current engines, a 40 percent weight reduction and a 20 to 30 percent lower specific fuel consumption were targeted. An integral inlet particle separator was another requirement. In addition, significant improvements in reliability and durability and reductions in required maintenance man-hours were stipulated. A program was launched to establish the feasibility of a new engine meeting these requirements.

Competition Conducted

Following competitive demonstration programs, General Electric's T700-GE-700 design (Figure 1) was selected and development began in March 1972. The engine was production qualified in early 1976.

In addition to powering the Sikorsky Black Hawk (formerly UTTAS), the T700 has been selected to power the Army's Hughes built twin engine AAH (Advanced Attack Helicopter) and, more recently, the Navy's LAMPS (Light Airborne Multipurpose System) twin engine helicopter, also to be built by Sikorsky.

Simplified Design Reduces Cost

General Electric achieved a significant cost reduction in the T700 through simplified engine design that involves less than half the parts of a comparable "first generation" engine. The benefits of using fewer parts mushroom throughout the engine life cycle and include significant logistics efficiencies.

The use of blisks makes this huge savings in number of parts possible. The five stage axial compressor is comprised of four blisks (Figure 2). One blisk combines two blades—thus making up the five stages. Each of the blisks forms a drum type of structure secured by mating surfaces and tiebolt to a single stage centrifugal impeller.

During the development program, more than 130 compressor rotor sets were fabricated by conventional methods from forgings to form finished blisks and impellers. Since these conventional methods were slow, GE conducted concurrent studies to identify T700 components that would be adaptable to more advanced production methods in order to obtain higher quality at lower cost. The blisks and impeller were selected as prime candidates for milling and finishing by automated procedures utilizing numerical control methods. A proposed program to develop such procedures was submitted to AVRADCOM in February 1975.

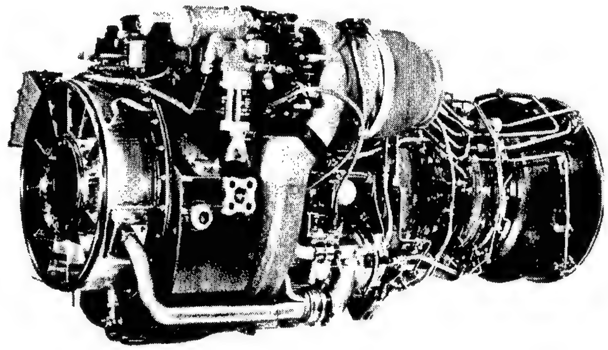


Figure 1

Special Technique Provides Savings

As a result, the Army selected GE to develop a multiaxis, multispindle numerical control milling technique to produce blisk and impeller airfoils. Funding was provided by AVRADCOM. The objective was to increase productivity to meet T700 projected production needs and, at the same time, reduce costs. General Electric wrote specifications for a five axis, four spindle, numerical control milling machine which was built by the New England Machine and Tool Company and delivered to GE in December 1976. This machine is shown in Figure 3.

Two closely related tasks were pursued at the same time:

- Development of abrasive flow machining by Dynetics Corporation and GE engineers to obtain the required airfoil surface finish and contour (the machine developed is shown in Figure 4).
- Selection of special equipment for inspection of the complete airfoil.

Completion of the first Stage 1 blisk successfully demonstrated capabilities of the numerical control milling and finishing machines. This new automated process differs markedly from the conventional fabrication of blisks.

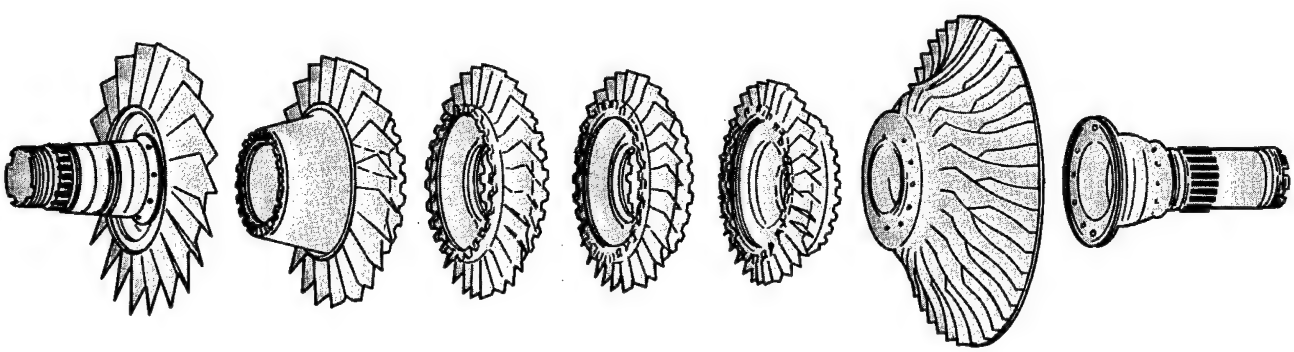


Figure 2

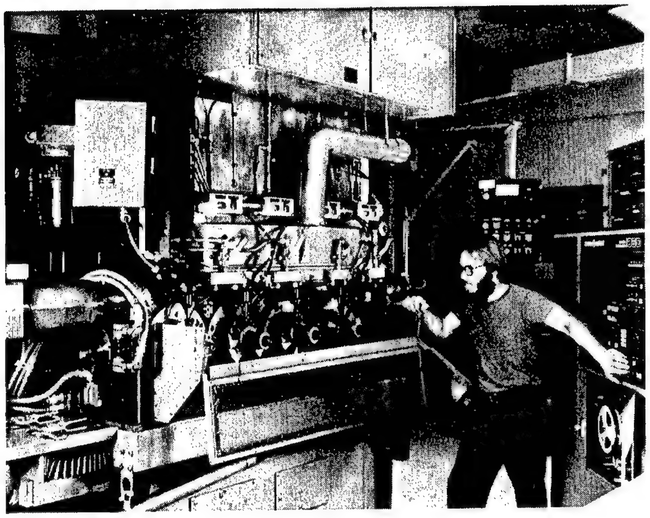
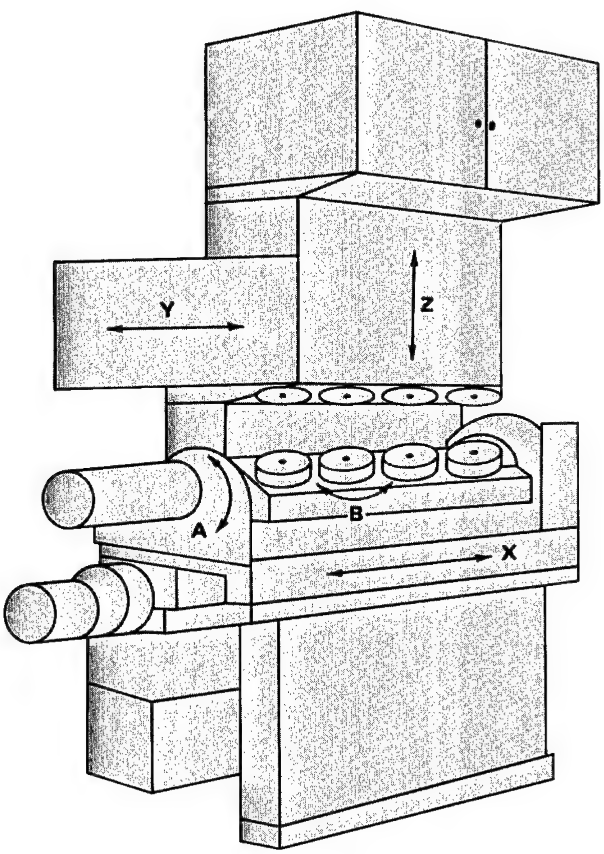


Figure 3



Conventional Methods Costly, Inefficient

Using conventional methods, blisk forgings are turned to a rectilinear shape and inspected ultrasonically prior to semifinish turning of the airfoil area. The blades are then rough milled on a tracer miller and contour milled with a hand pantograph assisted milling machine one piece at a time. The proper shape and dimensions are obtained through in-process inspection of the airfoil, using a manual tracing stylus/comparator.

Finish turning, drilling, and grinding are done on conventional equipment. The required airfoil surface finish is obtained by hand polishing, while blade leading edge and trailing edge profiles are hand filed to the proper contour with the control aid of optical devices.

The impeller follows the same rough and finish machining processes, except that rough milling is replaced by electrodischarge machining, and coating is not required.

The complete conventional machining cycle involves operations at five widely separated geographic locations. Parts are inspected at the source prior to delivery for coating, curvic grinding, and balancing. There is a risk of damaged or lost parts, and shipping charges increase part costs.

Automation Brings Togetherness

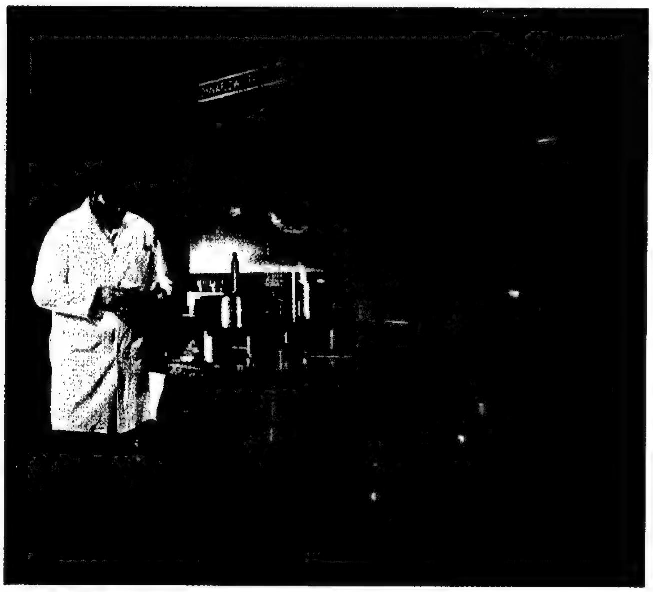
The new automated process insures consistent high quality, the specified production rate and a significant cost reduction. This new approach introduces a complete manufacturing center utilizing computer directed numerical control equipment. With everything done at one location and the operations automated, efficiency is vastly improved.

Blisk forgings are machined to within 0.125 inch minimum envelope of their rectilinear configuration on a heavy duty numerical control dual spindle vertical turret lathe. Ultrasonic and magnaflux inspections precede finish turning on a numerical control slant bed turret lathe. A special grinder fitted with index plates performs slotting operations. Splines for Stage 1 are cut by a precision gear shaper.

Airfoils are formed from the solid disk on a five axis, four spindle numerical control milling machine using successive program tapes that control the rough and finish operations in proper sequence. The first pass roughs and finishes every other "pocket" (space between two adjacent blades). These pockets are filled with a matrix that melts at low temperature. This matrix provides maximum rigidity for the second pass during which the remaining pockets are machined. After this pass, the matrix is removed and recycled.

Airfoil Process Complex

This airfoil forming operation is the most difficult and sensitive in the entire process. Airfoils have complex shapes, high twist gradients, large camber, and close spacing, and they require precisely machined three dimensional contours. Trailing edges may be as thin as 0.006 inch, and the profile of leading edges must be aerodynamically acceptable. In addition, machined airfoil outlines must be closely coordinated with abrasive flow characteristics in order to consistently achieve the desired contour within design tolerances. The machining program accounts for each of these vital considerations.



After the airfoils are milled and prior to abrasive flow machining, a detailed inspection determines the quality of the "unfinished" airfoils and provides input to a data base for fine tuning of both the milling and surface finishing processes. A minimum of three airfoil sections are measured (just above platform, at mid-span, and near the tip) for chord length, thickness, leading and trailing edge profile, contour relationship to stacking axis blend radii at platform, and platform distance from the rotor axis. These same characteristics are measured and recorded after abrasive flow machining to check final inspection criteria. Adjustments to the program tapes are made easily and quickly to bring part sizes within dimension specifications given on drawings.

Full-Scale Production Next Goal

With the process now developed to a point where parts are consistently within design envelope tolerances, the goal has become development of a full-scale production facility, with production rates reaching 70 plus engine sets per month in the 1985 time frame. The program is geared to process blisks from raw material to finished, engine ready parts at a single production facility.

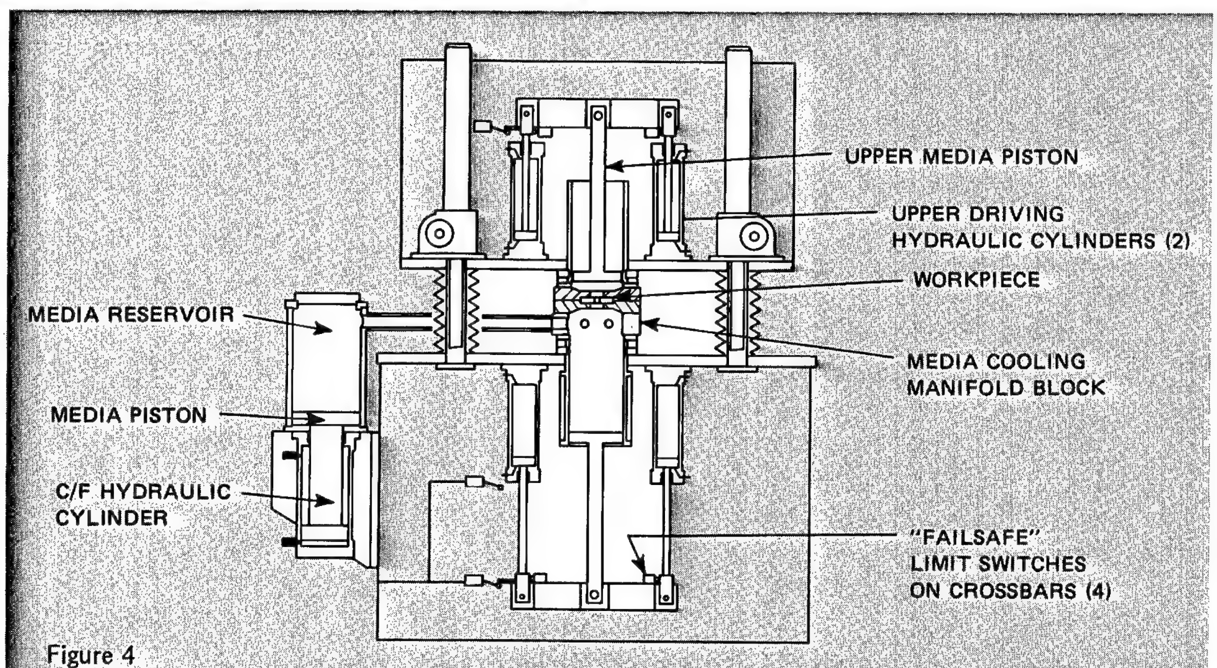
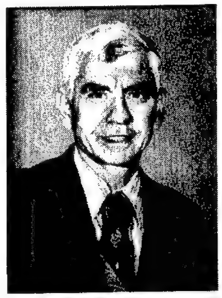


Figure 4

Erosion Resistant Clad Rotor Blades



GERALD A. GORLINE is a graduate Industrial Engineer with BSIE (1959) and MSIE (1966) degrees from Washington University, St. Louis. He has been responsible for managing the AVSCOM and AVRADCOM Manufacturing Technology Program during the past twelve years. In addition, he has served as project engineer for the development of advanced manufacturing technology projects for CAD/CAM and engine and aircraft components used in Army helicopters. He has twenty years of manufacturing engineering experience of which seventeen are in the aerospace industry involving both fixed wing and rotary wing manufacturing areas with aerospace firms and with the U.S. Army. He is active with the Aerospace Division, American Institute of Industrial Engineers, and the American Helicopter Society. He also is a member of the Metals Committee of the Tri-Service Manufacturing Technology Advisory Group (MTAG).

EDITOR'S NOTE: Mr. A.R. Stetson, Chief, Materials Engineering, Solar Turbines International, participated as coauthor of this article on clad rotor blades.

When helicopters operate in heavy rains or in continually dusty and sandy conditions, erosion of rotor blade leading edges is a major problem. New research at Solar tells us that the addition of boride coated titanium cladding to the leading edge vastly improves erosion resistance. Researchers at Solar are looking at the rain and dust erosion problem in a continuing manufacturing technology study for the Aviation Research and Development Command.

The coated surfaces developed at Solar (the coatings are designated Solar Solide™) are extremely resistant to dust erosion and are unaffected by subsonic rain. Coating life alone is up to 25 times greater than the lives of present uncoated cladding alloys. With the titanium substrate providing further protection, coated clad life is even longer. The potential for large savings in operational maintenance costs is great.

In addition to the coating material and coating process, Solar has worked out manufacturing processes for forming and attaching the cladding. They are now completing work on bonding full-scale cladding to UH-1H and UTTAS rotor blades.

Rain, Dust Severe Problems

Rain and dust erosion are very real enemies of helicopter rotor blades. The blade tips of aircraft operating over sandy terrain can be destroyed in just a few minutes. Rain erosion is not quite as serious, but still remains a problem. With recent improvements—e.g., the use of stainless steel, electroformed nickel, or titanium alloys rather than aluminum —the resistance of leading edges to subsonic rain erosion has increased ten times or more. No current protective systems offer comparable improvements in resistance to dust.

Boride Coatings Do The Job

Figure 1 compares rain and dust erosion resistance of various leading edge claddings as determined in whirling arm rig tests. Looking quickly at such data, one might think we are well on the road to solving the erosion problem. But not so. Let's look a little more closely at the figures.

The test data realistically represents severe conditions that will be encountered in service. Rain tests were run for up to 10 hours in a 25 mm/hr rainfall (drop size ~2 mm). Dust erosion tests were run in Arizona road dust No. 40 actually sucked up by the rotating blades from troughs located across the diameter of the test equipment.

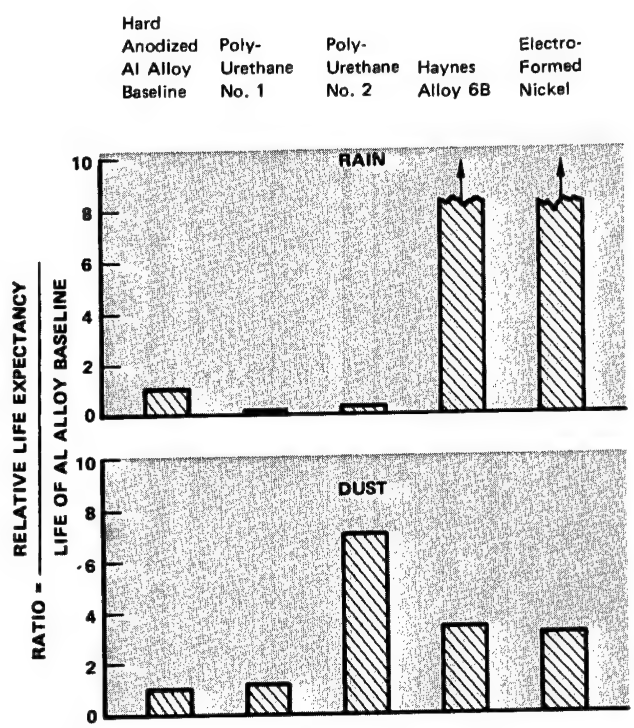


Figure 1

Severe Life Short

With the aluminum alloy, the rain completely penetrated 0.63 mm of cladding in less than 1 hour. Dust was much quicker—complete penetration in less than 4 minutes. Thus, although the two metallic clads shown (cobalt and nickel) significantly improve rain and dust erosion resistance, their life under severe hovering conditions would still be extremely short—no more than 12 minutes. Not very encouraging to a pilot flying low-level operations in the desert.

Furthermore, studies of metal erosion offer little hope that changing from one structural alloy to another will improve dust erosion resistance. As we have seen, the change from an aluminum alloy to a cobalt or nickel base alloy, although it offered threefold improvement, hardly solved the problem. A lot more improvement than that is needed.

Boride Coatings To The Rescue

Earlier work at Solar showed that boride coatings on 410 stainless steel and 17-4PH alloys improved the base alloy dust erosion resistance by 20 times. (Tests were conducted with dust moving at 215 m/sec, the same velocity used for the tests shown in Figure 1). This represents an improvement of 60 times over the hard anodized aluminum alloy and 20 times over the electroformed nickel noted in Figure 1. With such obvious potential, AVRADCOM/AMMRC funded an initial process evaluation and then a manufacturing technology program at Solar to pursue the coating process.

Initially, four alloys were considered as potential substrates for the boride coating—AISI 1010, SAE 410, SAE 430, and Ti-6Al-4V. These cladding materials were used in thicknesses of 0.25 mm and 0.50 mm. Solar used their M9-13 process to apply various thickness coatings, with 0.05 mm coatings for the steel and 0.013 mm coatings for the titanium alloys showing the most promise.

The alloys 0.25 mm thick soon were eliminated for two reasons. First, there were distortion problems in handling. Second, helicopter manufacturers, who typically use metal clads from 0.63 to 1.00 mm thick, expressed little interest. AISI 1010 and SAE 410 were also eliminated. These steels offered no advantage over SAE 430 or the titanium alloy and were less corrosion resistant.

Erosion Tests Tell The Story

Airfoil shapes of coated SAE 430 and Ti-6Al-4V were bonded to both fiberglass epoxy and aluminum alloy blade material for rain erosion testing. The rainfall rate for these tests was 25 mm/hour, with 1.8 mm diameter raindrops. The specimen velocity was 230 m/sec; the tests continued for 1 hour. There was no visual or microstructural damage to either specimen.

Dust erosion tests were also conducted. The results are shown in Figure 2. Uncoated baseline materials were included in these tests for comparison. The vastly improved erosion resistance of the coated alloys is clearly shown. The improvement is further illustrated in Figure 3, which shows the relative life expectancy of coated and uncoated alloys in a severe dust environment. Coated alloys can be expected to last from 8 to more than 25 times longer than uncoated alloys.

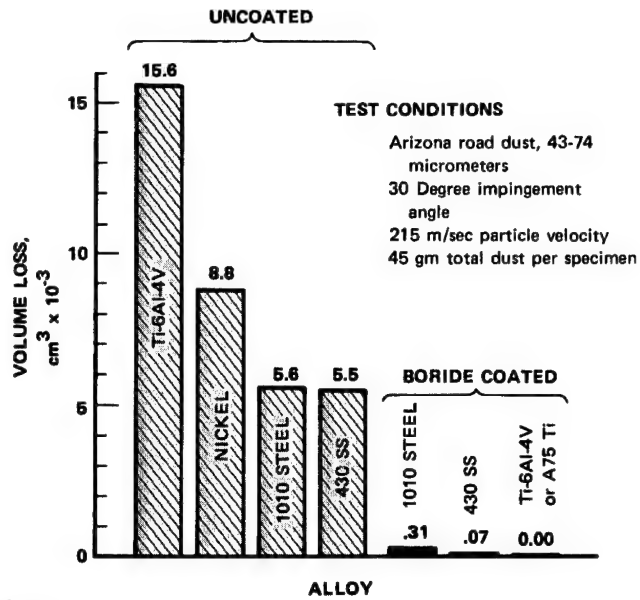


Figure 2

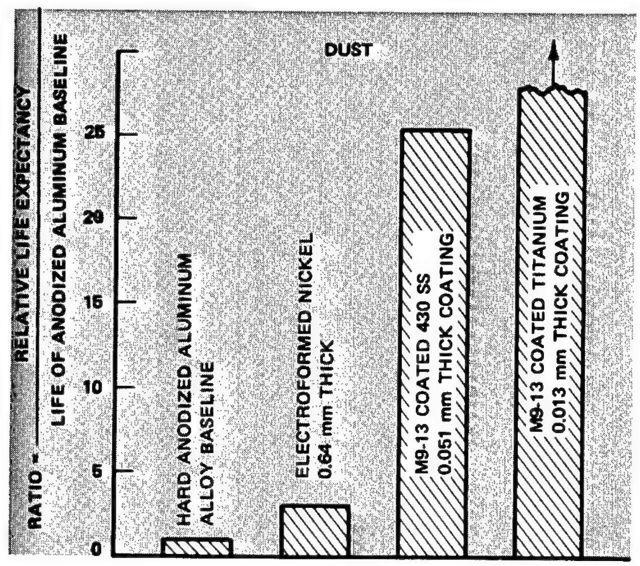


Figure 3

In a very recent test, the coated alloys were compared with hard chromium plate, which is currently used to surface axial blowers in coal fired boiler exhaust purification systems. Results of these tests, (Figure 4) are quite significant. Under the conditions shown, more than 15 times as much dust impinged on the specimen as during the tests noted in Figure 2. This indicates very long life, particularly for the coated titanium alloy where the ratio of material removed to material impinged is ~1 to 1,000,000.

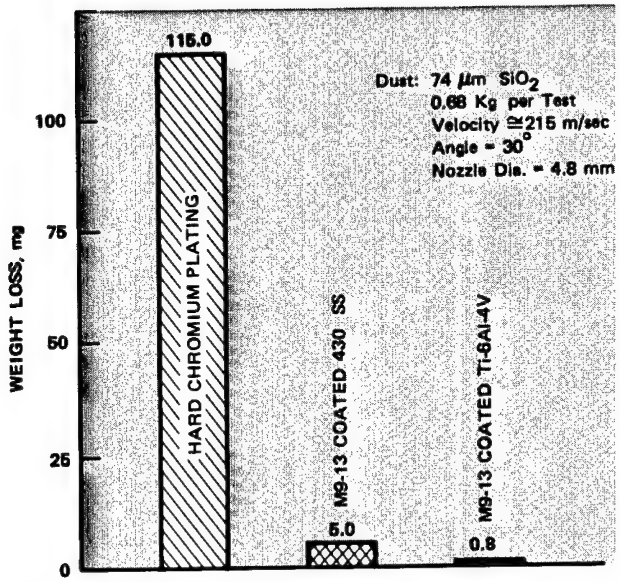


Figure 4

Erosion Resistance/Cost A Tradeoff

It is important that the cladding be able to flex with the structural member without loss of erosion resistance. Tests were conducted to measure the influence of strain in the coating on the dust erosion resistance. Specimens were strained to 10,000 micrometers per meter in air at room temperature, well beyond the proportional limit of the coating, and subsequently dust erosion tested. The results were the same as those shown in Figure 2 for as coated 430 stainless steel and Ti-6Al-4V.

Solar also has conducted tests to determine the energy threshold at which significant coating damage occurs with various thicknesses of coatings. They have found that the energy threshold for a coating 0.028 mm thick is more than an order of magnitude higher than for a coating 0.013 mm thick. On the other hand, the process time for the 0.028 mm coating is 56 to 64 hours, compared with about 4 hours for the 0.013 mm coating. The tradeoff between production cost and erosion resistance must be carefully weighed in the design process.

Other Properties Also Evaluated

Because the claddings are not structural parts, their mechanical properties were considered as secondary. Thus, a loss in ductility and marked reduction in fatigue life for both alloys were not considered significant. Yield and tensile strength were not markedly affected by the coating process.

Solar has successfully bonded the coated claddings to Ti-6Al-4V, 2024-T4 aluminum, and epoxy-fiberglass substrates with a number of commercially available adhesives. Epoxy films have proven to be the best adhesive for the purpose and the most convenient to use. In extended salt spray tests, 430 stainless specimens have shown only slight evidence of corrosion, and the titanium alloy specimens have shown no corrosion. The 2024-T4 aluminum alloy was severely corroded in this environment.

Production Technology Developed

With the advantages of boride coatings proven, Solar is seeking to develop the manufacturing technology needed to utilize the process in production. This has been a two-stage development effort, with the second stage still in progress.

In Stage 1, Solar applied the coating to small leading edge shapes to assess problem areas. SAE 430 and Ti-6Al-4V were used in thicknesses of 0.5 mm and cladding widths of 50 to 100 mm.

During Stage 2, Solar is scaling up the process to coat 76 cm long leading edge claddings of Ti-6Al-4V or A75Ti alloys for the UH-1H and UTTAS helicopters. These claddings are 1 mm thick. At the same time, Solar is investigating methods of bonding the cladding to epoxy-fiberglass and metallic blades. The coating parameters used during both stages are shown in Table 1.

Alloy	Process Temperature	Process Time, hrs	Coating Thickness, mm
SAE 430	925 C	4	0.05 ± 0.01
Ti-6A1-4V	1149 C	4	0.013 ± 0.003
A75Ti	1149 C	4	0.013 ± 0.003

Table 1

Distortion Problem Overcome

It became apparent very early in Stage 1 that an airfoil shape could not be maintained during the coating cycle without restraints to prevent bowing or flaring. Such distortion resulted from weakness of the alloys at the coating temperature and from creep stresses caused by growth of the coating. Figure 5 illustrates what happens when unsupported airfoils with a chord height of more than 5 cm are coated. This difficulty was overcome with columbium alloy support tools, such as the one shown in Figure 6.

The airfoil shapes also required coating on both sides of the clad to prevent distortion. With one sided application, volume growth of the coating and differential expansion of the coating and the substrate caused severe distortion. On all substrate alloys, the coating is in compression at room temperature.

The Stage 1 activities showed that precise tolerances were maintained during the coating process. The claddings were readily bonded to fiberglass-epoxy and metallic (brass leading edge plus aluminum spar) substrates with standard tape type adhesives. Figure 7 shows various bonded configurations.

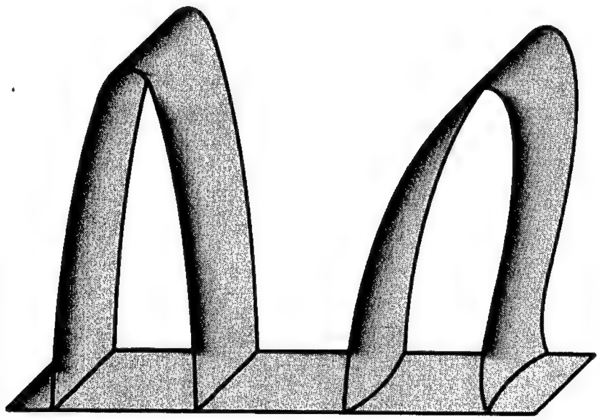


Figure 5

Improved Tooling Needed

With the larger cladding investigated in Stage 2, the spaced columbium alloy internal supports, such as those illustrated, did not prevent sagging at the processing temperature. These longer claddings required complete support over their entire length. This was accomplished using male and female graphite dies, as shown in Figure 8. With these dies, specimens retained precise dimensions during the coating process.

When tooling was prepared for the 76 cm long leading edge claddings, no preformed claddings were available for the UH-1H blades. Therefore, experimental tooling was designed that combined creep forming of the cladding with the coating process. Figure 9 shows the design of this tooling. During the coating sequence, a slightly bent A70Ti alloy blank was placed in the die and then run through the coating cycle. In this way, the claddings were creep formed to precise tolerances during coating.

Other Blade Shapes Tried

The other blade shape under consideration is an experimental UTTAS configuration of an epoxy-fiberglass type with a Ti-6Al-4V leading edge. In this case, it was possible to cryogenically strip the leading edge from the blade as a preform for the coating studies. With these preforms, initial efforts used only a male graphite mandrel for forming.

Two problems arose. First, the cladding separated from the mandrel during processing. As a result, it did not conform to the blade closely enough to allow satisfactory bonding. Second, the coating thickness was not uniform from side to side. These problems were resolved using a wide female mandrel.

The program is now in its final stage, with adhesive bonding of the 76 cm long claddings to the blade still to be done. Another important step now under way is evaluation of test specimens by three major helicopter manufacturers—Hughes, Sikorsky and Bell Helicopter Textron. Since such companies will be the ultimate beneficiaries of the new technology, their evaluation is a vital step in its ultimate use as a production process.

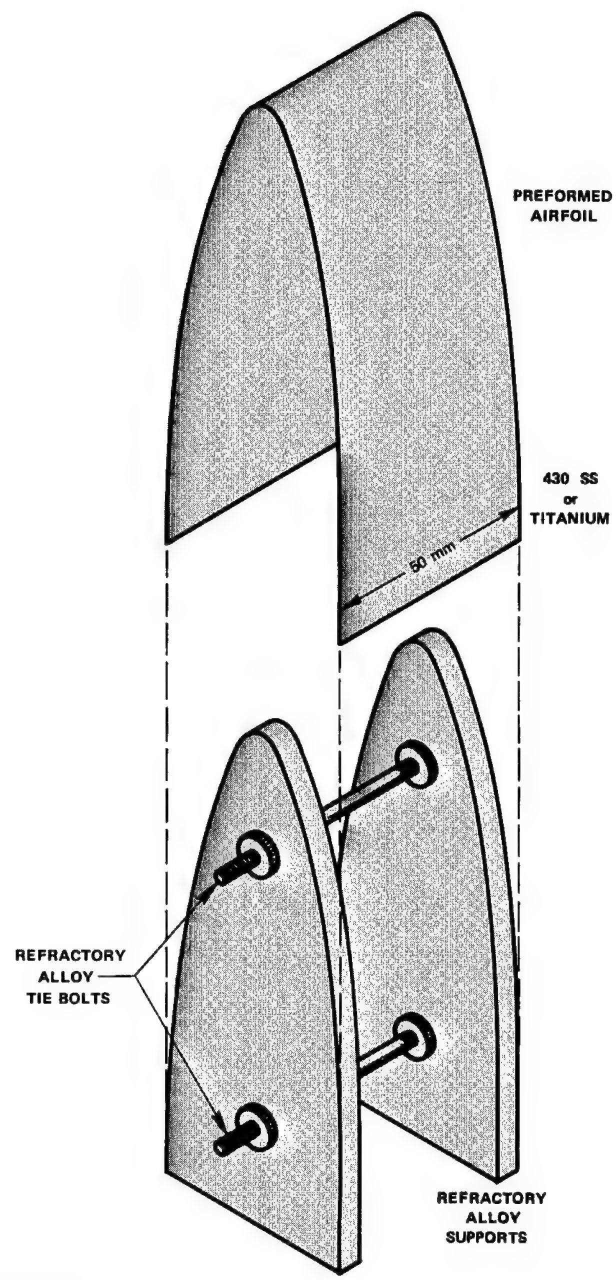


Figure 6

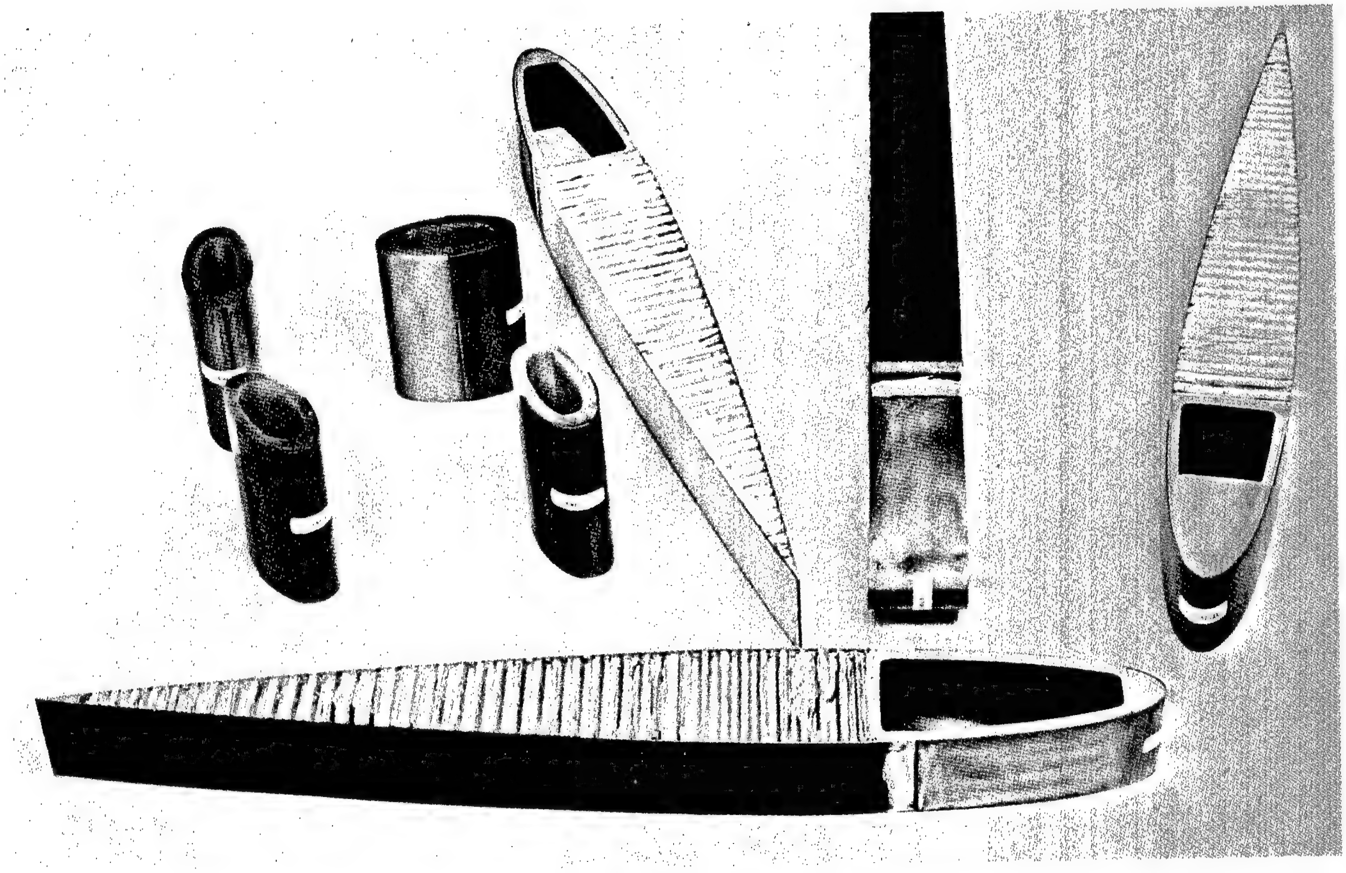


Figure 7

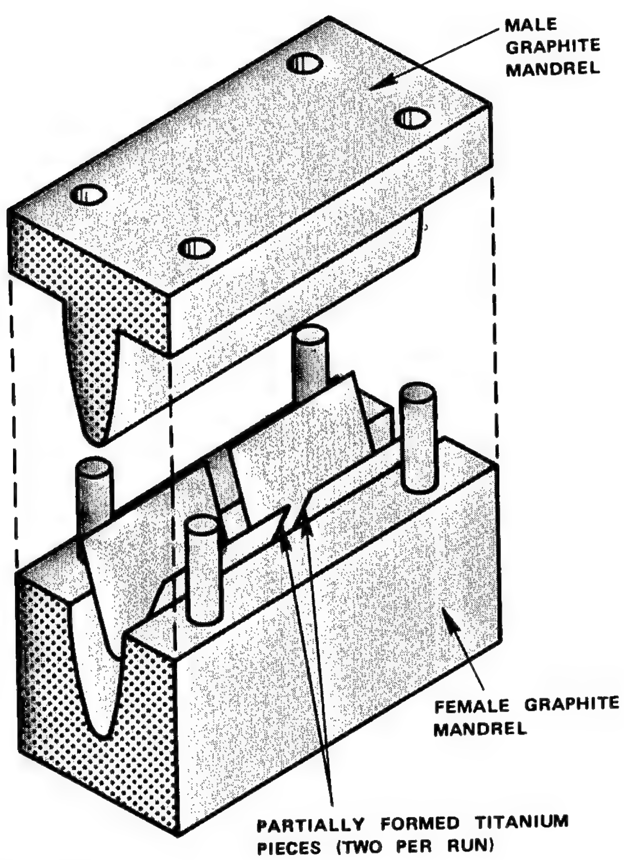


Figure 8

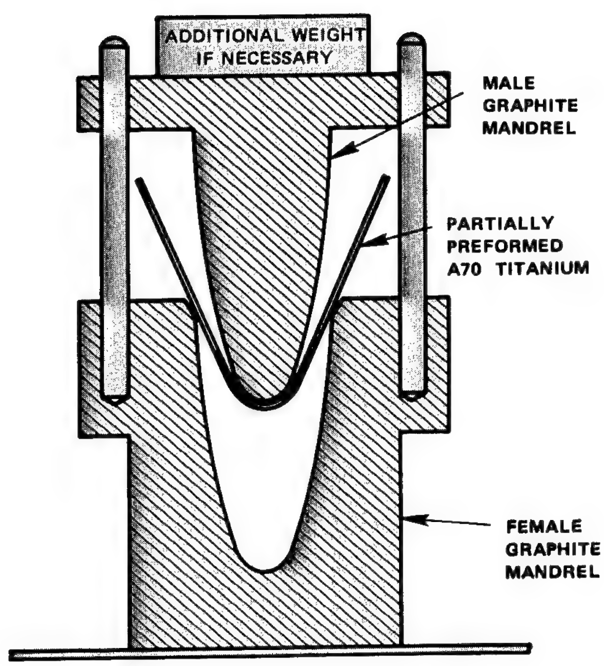


Figure 9

Production, Life Cycle Savings

Precision Forging Cuts Gear Costs

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Does 60 percent material cost savings on aircraft gear manufacture sound interesting? Or 33 percent man-hour savings?—All with no loss in performance?

Work at TRW for AVRADCOM indicates such savings are possible when precision forging is substituted for conventional forging methods. Additional savings in life cycle costs are realized by making matched sets (gear and pinion) for replacement rather than requiring totally interchangeable gears.

Recent emphasis in aircraft gear production has been on improving load capacity and reliability, reducing weight, and maintaining total interchangeability. Cost considerations have been of secondary importance and, consequently, costs have been on the rise. High precision and total interchangeability equate with high costs.

Interchangeability, Spiral Bevel Gears Dominant

Part of the need for this high precision arises from that requirement for totally interchangeable gears. In order to satisfy this need, American Gear Manufacturing Association (AGMA) Class 12-13 gears are required. These classes of gears require that a composite tooth to tooth measurement tolerance on the order of ±.0003 inch be maintained. Keeping things this close necessitates a time consuming series of machining and checking operations that boosts costs skyward.

The total interchangeability requirement isn't the only cause of high gear manufacturing costs, however. Another reason is the widespread use of bevel gears which are utilized to transmit power between intersecting shafts. Spiral bevel gears are more widely specified than straight bevel gears. Because of their continuous contact, the spiral bevel gears have a larger load carrying capacity and run more smoothly and quietly than straight bevel gears of the same size. But fabrication of the spiral bevel gear form is a precise and time consuming operation.

In conventional production, the spiral bevel gear form is machined from a forging, surface hardened and heat treated, and then finish ground. The machining and finish grinding involve repeated processing and checking to meet tolerances. AVRADCOM engineers felt that by turning to matched set replacement—thus relaxing the tolerance requirements—and by developing improved manufacturing methods, they could take a big chunk out of those costs induced by the tedious repetitive processes.

Less Chips By Pressure Method

AVRADCOM initiated a manufacturing technology project to investigate these possibilities. The objectives were to eliminate excessive chip removal operations and reduce tooth cutting operations by developing precision forging methods.

Two methods were investigated. The first involved high energy forging techniques using an air pressure press. It became evident that successful use of such techniques would require an extended development effort. Initially, problems with premature die failure causing deformation of the spiral bevel tooth form were overcome. Then the preproduction forging revealed problems with progressive upsetting and bending of the spiral bevel pinion tooth due to high forging forces. The dimensional integrity of the die cavity could not be maintained.

Mechanical Means Superior

Mechanical press forging, the second method, has proven more successful. This effort was contracted to TRW with Boeing Vertol subsequently testing the parts. Forgings were made on a mechanical press using two forging blows in rapid succession, with no reheating between blows. The process produced forgings with integrally forged tooth forms. After forging, the parts were heat treated and finish machined in the same manner as conventionally produced gears. Comparison of the process with conventional forging indicates a 33 percent savings in manufacturing man-hours and 60 percent material cost savings.

Precision forged gears have been tested for deflection, rotating load, and extended surface fatigue. The results show that their surface load capacity is at least equivalent to that of conventionally produced gears. Equal performance at greatly reduced cost makes precision forging a very attractive alternative to standard production methods.

Matched Sets Reduce Tooth Grinding

Production costs are further reduced by going to the matched set replacement concept, since the tolerance requirements are not as close as those required for totally interchangeable gears. Usually, as the gear sets are used, defects that develop in either the gear or the pinion are mirrored in the other; both components must be replaced approximately 65 percent of the time. So the large amount of time spent making sure that all gears and pinions are compatible is actually wasted.

Under the matched set concept, gears will be precision forged and then ground and honed to remove scale and to prepare the surface for a carburizing and hardening heat treatment. A rapid honing process to remove all distortions induced during heat treatment will follow. Surfaces other than gear teeth will then be machined. A gear and pinion set will be run together in a short lapping operation. Black oxide will then be applied to the gear and pinion and they will be stored as a set until needed.

Using the approach cited above, an AGMA Class 8 gear can easily be produced. A composite tooth to tooth tolerance on the order of ±.001 inch would be maintained. As can be seen in Figure 1, the cost for the production of a totally interchangeable gear (AGMA Class 12-13) is approximately five to seven times that of a gear produced for the matched set approach (AGMA Class 8).

Implementation of the manufacturing methods described will ensure production of high quality gears at reduced cost. Elimination of the total interchangeability requirements will allow life cycle cost savings to be realized.

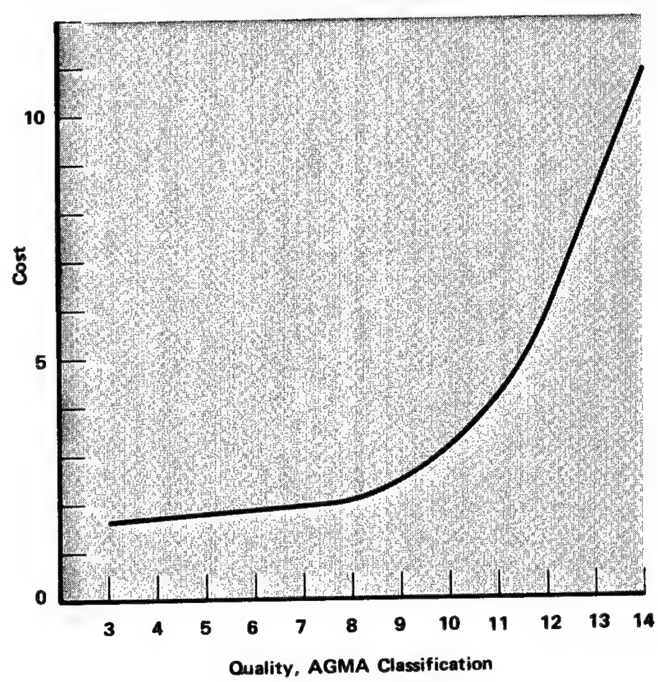
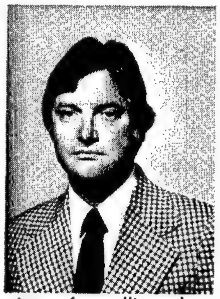


Figure 1



JOHN J. LUCAS, Chief of Metals, Engineering Department, Sikorsky Aircraft, received a BSME from Villanova University in 1971 and has since taken extra courses at Bridgeport Engineering Institute. He joined Sikorsky in 1961 as a Structural Test Engineer. In this position Mr. Lucas was responsible for research into the statistical planning and interpretation of results of full-scale fatigue tests of various helicopter components and subsystems. He also was responsible for R&D activities conducted by whirl testing of experimental and production main and tail rotor systems. In 1967, Mr. Lucas became Supervisor of the Materials Properties Group with the responsibility for all physical, static, and fatigue test evaluations of metallic and nonmetallic materials conducted at Sikorsky. In 1970 Mr. Lucas became supervisor of the Materials Development Section. In 1976, Mr. Lucas assumed his present position as Chief of Metals. He is responsible for all development, testing and design support activities concerning new and current metallic materials and process applications at Sikorsky. He is a member of the American Helicopter Society, Pi Tau Sigma (National Honorary M.E. Society), American Society for Testing and Materials, of which he is an active member of Committee D-30 on "High Modulus Fibers and Their Composites", The Society of Aerospace Material and Process Engineers, and the American Society of Metals.

MARON J. BONASSAR, Senior Materials Engineer, Metals Section of Sikorsky Aircraft, received a B.S. in Chemistry from Fairfield University in 1958. He joined Sikorsky Aircraft in July of that year as a Materials Engineer in the Materials and Process Section. In this position, he was responsible for the design, layout, and direction of laboratory investigations and test programs used in the evaluation of materials and processes appropriate for use in aircraft design and manufacture. In 1973, he assumed his present position in the Metals Section. Current responsibilities include the management and coordination of two Army programs: Continuous Seam Diffusion Bonding of Titanium Structures (Contract DAAG46-76-C-0016) and Fiber Reinforced Plastic Helicopter Tail Rotor Assembly (Contract DAAJ02-76-C-0001). Mr. Bonassar has been involved in several Government funded contracts and programs and has authored numerous technical reports, including Army programs on "Forge Diffusion Bond Titanium Rotor Hub Evaluation", "Continuous Seam Diffusion Bond Titanium Spar Evaluation", and "Development of Adhesive Bonded Joint for Glass Resin Composite Sandwich Structures".

Fewer Controls, Easier Inspection

Diffusion Bonding Shows Cost Advantages

In a continuing manufacturing methods and technology (MM&T) program for AVRADCOM, Sikorsky Aircraft Division of United Technologies Corporation is evaluating continuous seam diffusion bonding as an alternate process for fabricating Ti-6Al-4V main rotor blade spars for the UH-60A BLACK HAWK® helicopter. The process offers two important advantages over the plasma-arc welding process now used, both of which are significant from the standpoint of cost reduction:

(1) Continuous seam diffusion bonding does not require the inert atmosphere and numerous process controls that are a must with the plasma-arc process.

(2) The flat, diffusion bonded joints are much easier to inspect than are the present contoured and irregularly shaped weld beads.

To date, Sikorsky* has successfully joined 10 ft spar tubes. Nondestructive inspection of these tubes indicates that high quality joints can be obtained. Fatigue characteristics have proven equally satisfactory and scale-up to full length(25 ft) spars is anticipated. The encouraging results indicate that continuous seam diffusion bonding could be a reliable, cost effective process for BLACK HAWK production. Furthermore, these results demonstrate that continuous seam diffusion bonding is a reliable manufacturing technique, with possible application to other Ti-6Al-4V aircraft structures.

Why Diffusion Bonding?

Titanium is a very attractive material for aircraft structures for many reasons. But, in order to increase its use, the cost of titanium components needs to be minimized. This requires development of alternative designs, manufacturing methods, and technologies that will conserve titanium, reduce the cost of hardware fabrication, and simplify process controls.

Solid state diffusion bonding is a process that allows fabrication of intricate titanium shapes by forming and joining single or multiple pieces. Joints can be obtained whose static and fatigue properties equal those of the parent metal. Many successful techniques are employed to exploit the advantages of solid state bonding, each with its own particular advantages and disadvantages. The continuous seam diffusion bonding process is one technique that appeared particularly applicable to production fabrication of the BLACK HAWK rotor blade spars.

Current Process is Complex

At present, these spars are formed by cold brake forming flat, 0.150 inch thick Ti-6Al-4V sheet to a circular shape. Then, the longitudinal seam is plasma-arc welded and the tube is creep formed to its final contour. Twisting the tube in an internally heated ceramic die aligns the joint with the flatwise neutral axis at the blade spar trailing edge. Finally, a composite cover with Nomex honeycomb core is added to obtain the airfoil configuration illustrated in Figure 1.

Plasma-arc welding was selected originally as a low risk solution for joining the seam in the titanium blade spar on the YUH-60A UTTAS prototype aircraft. This selection was based on information and experience acquired in 1971 during initial design of the aircraft. Looking toward future production requirements, several MM&T programs were completed that identified diffusion bonding as a potentially lower cost, reliable alternative to plasma-arc welding.

In the initial evaluation program† two 10" long, D shaped simulated spars 0.125 inch thick were hot formed and diffusion bonded. Fatigue tests confirmed the acceptability of the continuous seam diffusion bonding process for this application.

Joint Quality

In a subsequent program†† process variables associated with the continuous seam diffusion bonding operation were defined and investigated. The results demonstrated that good joint quality is obtained over a wide range of standard conditions of current, speed, and force. However, as expected, poor fitup and contamination can result in poor quality joints, even under optimum conditions.

Finally, nondestructive inspection techniques for these joints were investigated and evaluated.

Results††† indicated that state-of-the-art nondestructive inspection techniques are suitable for evaluating diffusion bond joint quality. Encouraged by the results of these programs, the present MM&T program** was launched—aimed directly at the BLACK HAWK spar.

How Continuous Seam Diffusion Bonding Works

Continuous seam diffusion bonding is a simple solid state process that involves local electrical resistance heating of material to a temperature considerably below its melting point. During heating, sufficient pressure is applied to cause diffusion of atoms across the joint, thus creating a metallurgical bond.

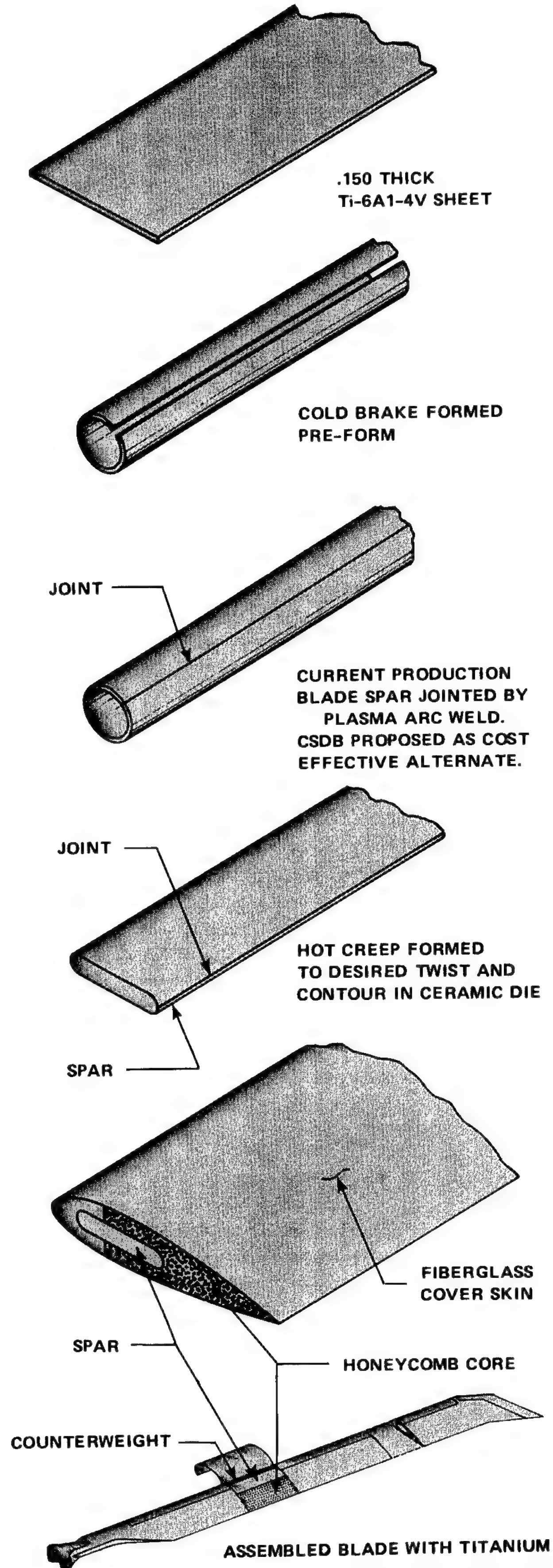


Figure 1

This process is accomplished, as illustrated in Figure 2, by placing the workpiece in a tooling fixture over a mandrel, which serves as one electrode, and passing it under an external wheel electrode. Current flows from the wheel through the joint to the internal mandrel providing localized heating.

Expansion Forces Restrained

Joining pressure normal to the bond line arises from the restraint of expansion force in the heated material under the wheel by the friction of the wheel surface and the rigid external tooling. Carriage speed, wheel current and force are adjusted to accommodate different materials, shapes, and thicknesses. Good quality bonds are obtained in air with no protective atmosphere. Proper control of temperature and pressure insures bonds of consistent strength and quality and makes the process suitable for production use.

From this concept the facilities and tooling for this program were developed as shown in Figure 3. This figure also shows the arrangement of materials on the tool prior to bonding. Titanium foil is placed on both the external and internal spar surfaces. Sandwiching the joint in this manner compensates for any difference in sheet thickness and for surface imperfections. Molybdenum foil placed on top of the titanium foils serves as a parting agent. Tantalum strips placed longitudinally on each surface localize the pressure and ensure adequate forging action in the joint area. The tantalum strips replaced steel strips which did not provide the heat and forging action needed for adequate bonding. All of the components are cleaned in a nitric-hydrofluoric acid solution prior to assembly.

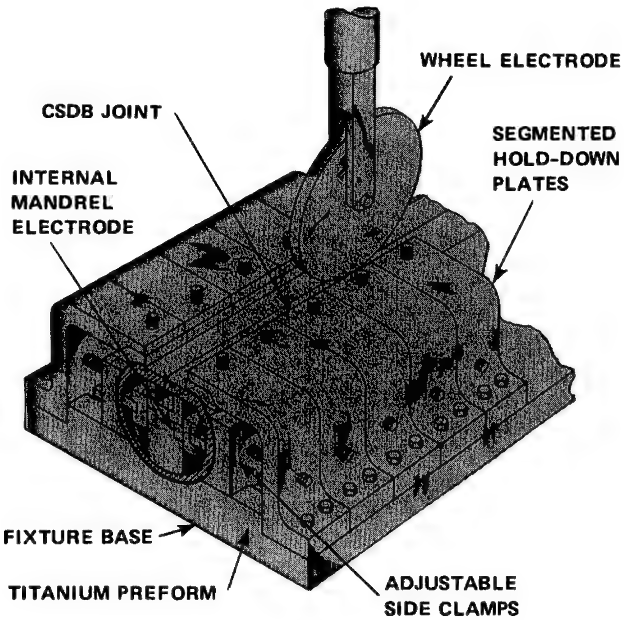


Figure 2

Preform Shape Key Element

The preform selected for use in process development is elliptically shaped and symmetrical about the centerline of the titanium sheet with parallel top and bottom surfaces, as shown in Figure 4. This shape provides the best tradeoffs between brake forming limitations and cost, bonding equipment, and tooling requirements. The objective was to minimize the tolerance requirements for the preform in order to minimize recurring production costs.

To obtain this shape, the titanium sheet is brake formed at the ends to the 90 degree position. It is then formed to an intermediate shape and final formed to the symmetrical configuration. Figure 5 illustrates this brake forming sequence.

Prior to forming, the sheet is milled and ground to a specified width, thickness, and length—width being the most critical dimension. The width must be such that drawing tolerances on the spar circumference are maintained while the edges of the sheet to be joined are perpendicular to the thickness surface. The milled, butted surface to be joined also requires a surface finish of 100 RMS or better.

Square, sharp edges are required for quality bonding, so the edges are not deburred. Rounded or chamfer edges produce a V-notch or groove that would cause stresses at the bond joint. The sharp edges subsequently are covered with vinyl strips for safety in handling, as shown in Figure 5.

Trial runs, as illustrated in Figure 6, indicated there would be no problem in creep forming this shape to the required airfoil configuration. It had been anticipated prior to the trial runs that the "flats" in the preform required for the continuous seam diffusion bonding tooling and wheel electrode could be troublesome.

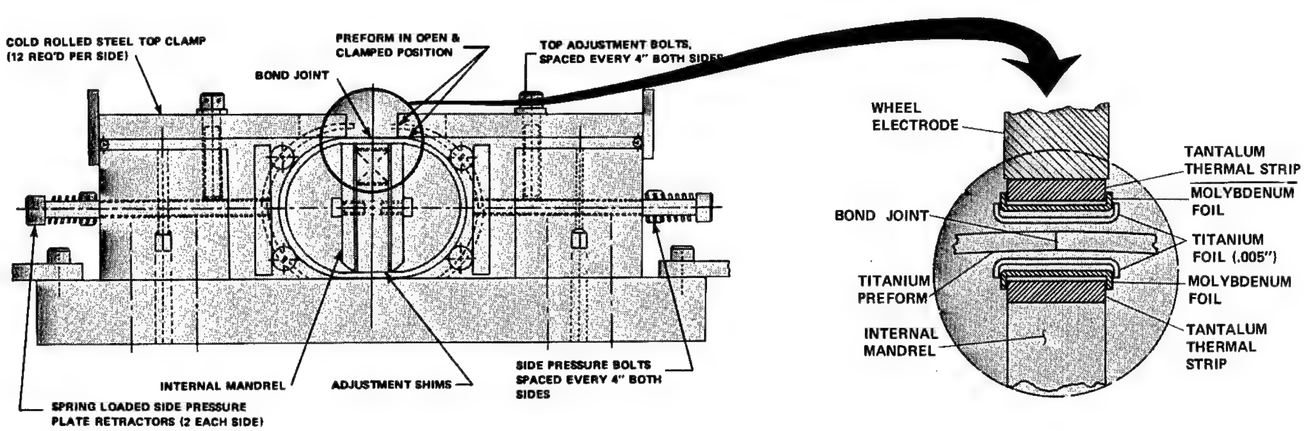


Figure 3

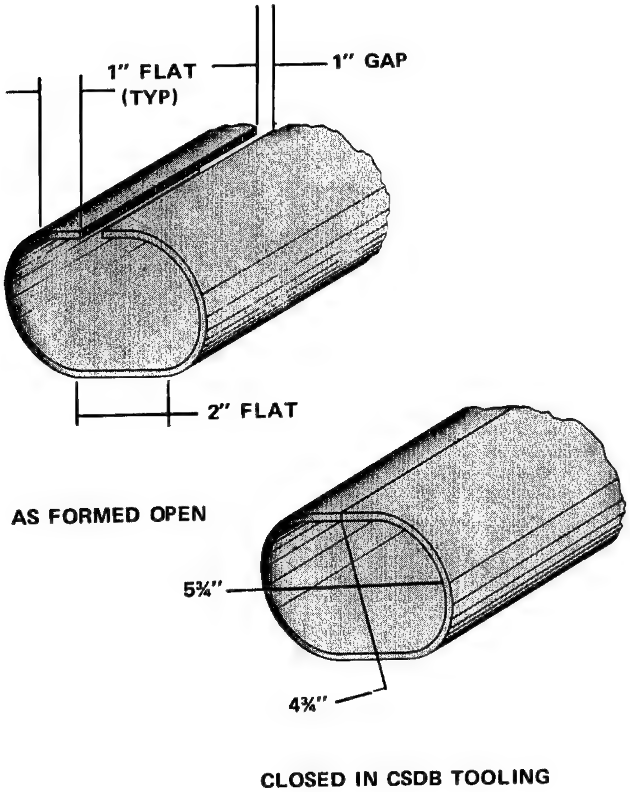


Figure 4

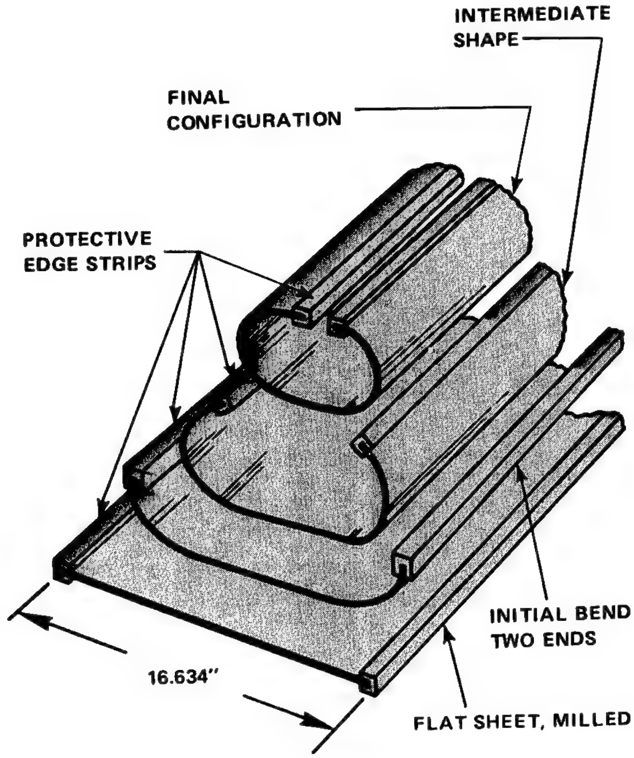


Figure 5

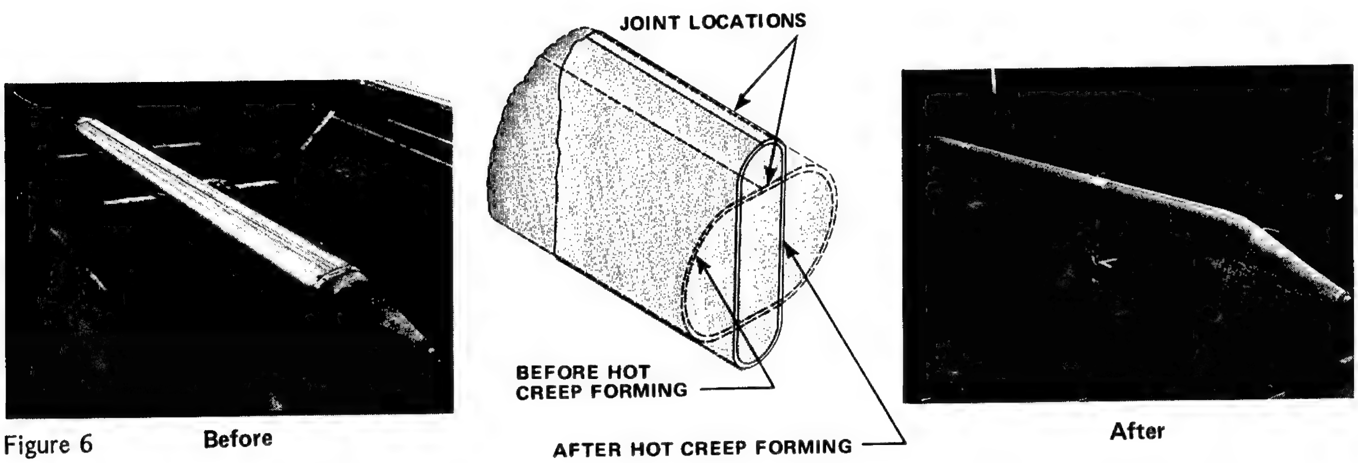


Figure 6

Process Parameters, Tool Design Selected

Initial studies using flat stock indicated that good joint quality is obtained over a wide range of standard conditions of current, speed, and force. However, it was determined that conditions such as nonparallel edge fitup, rounded corners, and gaps of preform edges must be carefully controlled to obtain good quality joints regardless of the bonding parameters used. Once the need for tantalum rather than steel thermal strips was identified, satisfactory bonds in three foot preforms were obtained using optimum conditions developed on the flat stock.

The fixture used for bonding, shown in Figure 3, consists of:

- A two inch thick aluminum base plate
- Four inch wide aluminum fixed vertical side blocks
- Adjustable one inch thick steel side vise clamps
- One half by nine by twelve inch segmented steel hold down top plates.

The preform is positioned and clamped within this fixture by adjusting the top and side bolts. The internal mandrel is a steel and copper rectangular unit measuring one half inch by four and three quarter inches by twelve feet. The final height of the mandrel depends on the internal height of the preform to be bonded. It is adjusted by attaching shim material to the mandrel base.

Preliminary Applications Successful

Three ten foot titanium preforms have been successfully fabricated and bonded using the materials, methods, and tools described. All of the tubes have been inspected by visual, borescope, fluorescent penetrant, radiographic, and ultrasonic techniques. No evidence of voids, nonbonding, or lack of diffusion was detected in the joint. Two tubes were examined by fatigue testing with one ten foot spar specimen and ten small-scale specimens tested.

Results of the full-scale ten foot spar test specimen are shown in Figure 7 and those of the small-scale fatigue specimen are shown in Figure 8. Both S-N curves indicate that the mean curve for the continuous seam diffusion bonded blade spars is well above the equivalent cruise flight and maximum measured maneuver condition on the BLACK HAWK aircraft, and that the continuous seam diffusion bonded blade spars are structurally adequate for use in UH-60A BLACK HAWK main rotor blades. The fatigue test results were satisfactory, and work is continuing on a follow-on effort. This effort is intended to scale up the facility and process to make production diffusion bonding of full length BLACK HAWK spars practical and to establish a basis for projecting production costs.

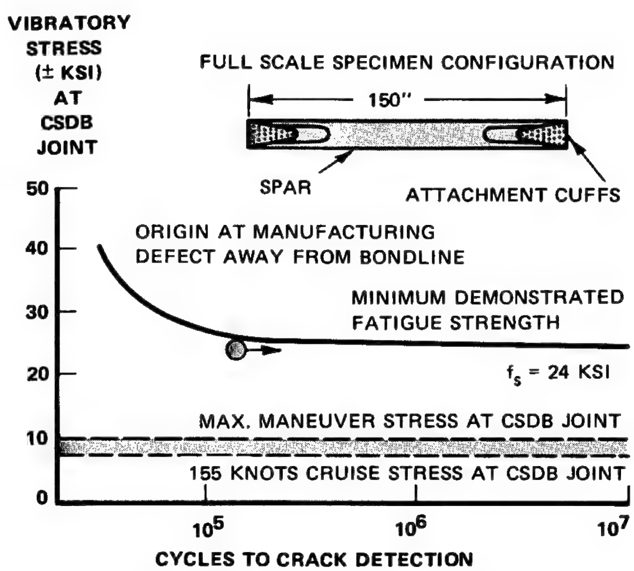


Figure 7

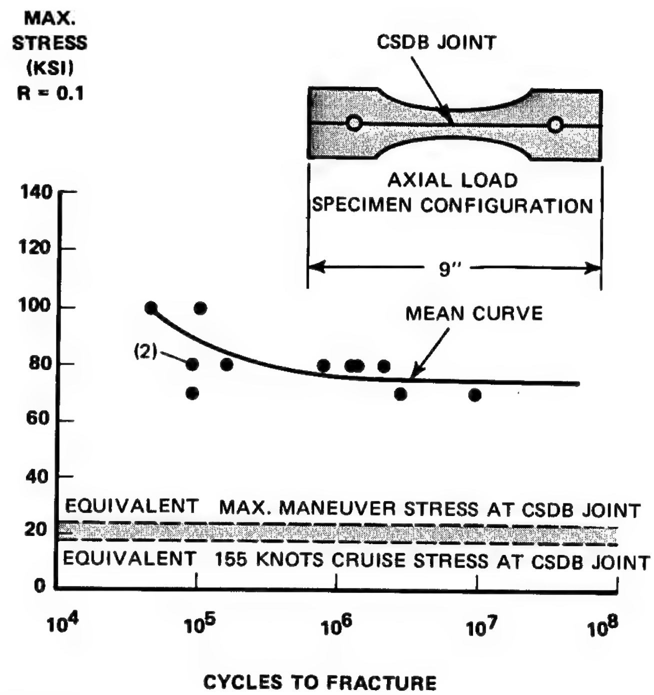


Figure 8

Acknowledgements

The sources for this article were

† Army Materials and Mechanics Research Center Report CTR 74-37 (April 1974), "Continuous Seam Diffusion Bond Titanium Spar Evaluation", by Maron J. Bonassar and J. Lucas (Contract No. DAAG46-72-C-0175).

†† Army Materials and Mechanics Research Center Report CTR 75-29 (November 1975), "Parametric Study of Diffusion Bonded Butt Joints", by M.E. Gulden, A.G. Metcalfe, and E.C. Thorsrud (Contract No. DAAG46-75-C-0040).

††† Army Materials and Mechanics Research Center Report CTR 73-53 (December 1973), "Nondestructive Testing Techniques for Diffusion Bonded Titanium Structures", by John A. Regalbuto (Contract DAAG46-73-C-0067).

* The actual bonding is being done under subcontract by Solar, Division of International Harvester.

** Contract No. DAAG46-76-C-0016, an Industrial Government briefing on the subject program, was presented at the MTAG Conference held in San Diego during November 13 to 17, 1978.

Brief Status Reports

NOTE: All the Brief Status Reports in this section are Manufacturing Technology projects sponsored by AVRADCOM.

Precision Filament Winding Resin Impregnation System. Current resin impregnation process control is on the order of ±4 percent in terms of fiber/resin ratio variance. The purpose of this project is to develop a resin impregnation control system that will provide control on the order of ±2 percent or better. By achieving consistency in the fabrication of composite structures, the current 4-to-1 margin of safety can be reduced. This will in turn reduce the weight and cost of composite structure fabrication. This work, being performed by Bell Helicopter Textron, will result in resin impregnation control system specifications and a breadboard control system. For additional information, contact Mr. Dan Haugan, (314) 268 -6476 or AUTOVON 698-6476.

High-Quality Superalloy Powder Production For Turbine Components. This project will establish an improved industrial procedure for producing high-quality superalloy powders to be used in the manufacture of hardware for gas turbine engines. Initial efforts are directed at removing nonmetallic inclusions from the earliest stages of melting. Subsequent efforts will be directed toward eliminating impurities from the powder making process. More than one powder making technique will be included. Techniques for cleaning impurities from the powder will be scaled to handle production lots. The final part of the program will be devoted to preparing process and product control specifications. Product evaluation will be carried out with specimens removed from hot isostatically pressed or forged parts representing turbine engine hardware. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Abradable Seals For Turbine Blade Tip Applications. The efficiency of gas-turbine engines such as the T-53, T-55, and LTS-101 can be improved significantly by building a replaceable, abradable seal into the turbine shroud. Operating and maintenance costs can be reduced as well. A method for manufacturing abradable seals is being investigated by AVRADCOM through AMMRC. The project is based on the extension of the effective use of abradable seals in the compressor section of large gas-turbine engines. This process will eliminate the precision machining necessary for providing the critical clearance required between the blade tip and the case shroud. For additional Information, contact Mr. Fredrick H. Reed, (314) 268-6476 or AUTOVON 698-6476.

Fluidic Servo Devices Applicable To Aircraft Stability Augmentation Systems. During this program, improved manufacturing technology was developed to produce reliable fluidic components for helicopter stabilization equipment. Results of the three-phased program, conducted at Honeywell, Inc., demonstrated the suitability of the electroform conductive-wax process, used in conjunction with conventional production processes, for the manufacture of fluidic systems. A pilot production line was set up and small "proof" production runs were completed. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

Ultrasonically Assisted Machining. The objective of this project is to determine the increased productivity and cost reduction attainable by using ultrasonic energy assistance to machine superalloys and difficult-to-machine materials. Candidate materials have been selected by canvassing aircraft and turbine engine manufacturers. Cutting parameters such as feed, speed, and cut depth will be determined for ultrasonically assisted machining. Cost effectiveness of this technology for making production helicopter parts will be evaluated against conventional methods and conclusions will be drawn regarding capabilities of the process capability. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Manufacturing Techniques For Helicopter Transmission Shaft Seals. Transmission seals are a continuing problem and one of the main reasons for early removal of transmissions. A promising approach to obtaining high-speed capability at low cost is the synergistic seal, which is a combined segmented carbon and elastomeric seal. The prime objective of this approach is to produce a low cost, high-speed seal at about one-third the cost of conventional high-speed seals. By installing segmented rings into an elastomeric member much of the precision machining of the mechanical seal can be eliminated. The purpose of this manufacturing program is to develop processes and techniques for molding the elastomeric element around the segments and to develop means to closely control the roundness and taper of the carbon bore and shaft outer diameter. For additional information, contact Mr. Fredrick H. Reed (314) 268-6476 or AUTOVON 698-6476.

Integrally Heated And Pressurized Tooling For Rotor Blades. Present technology for composite rotor blade fabrication calls for a time-consuming series of operations involving vacuum bag sealing and autoclaving of the material. This project will establish criteria for integrally heated and pressurized tooling to replace autoclaves in the process. The proposed process would eliminate the use of vacuum bag material by having an integral bag in the tool. The tool would be used as the cure fixture. Integrally heated and pressurized tooling will permit rapid heat-up and cool-down rates so that cycle times will be reduced. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

Advanced Adhesives For Transparent Armor For Army Air-Craft. AVRADCOM is developing manufacturing technology and production standards for fabricating film adhesives for use in laminated configurations for transparent armor applications. Various film adhesive materials have been developed and laminated test specimens are being tested at AMMRC. Tests include evaluation of thermal behavior, optical clarity, and ballistics characteristics. Flight testing will also be performed under this project. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Development Of Automated Process For Fabricating Tetra-Core Elements. Techniques and equipment were developed to automate the fabrication of tetra-core elements, which are a three-dimensional, filament wound/woven, fiber-reinforced plastic structure. These elements are used as fiber-reinforced-composite core material. A tetra-core machine was purchased from En-Tec, Incorporated, Salt Lake City, Utah, and installed at the Applied Technology Laboratory, Ft. Eustis, Va. Flat tetra-core panels were fabricated and distributed to industry for evaluation. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

Heat Treatment Of Steel Gears. The purpose of this program is to establish the heat treatment process best suited for advanced aircraft-transmission gear materials and other stringent applications with large-scale production. Carburizing gear test specimens of 9310 and Vasco X-2 steel were fabricated, heat treated, and tested. Rolling contact fatigue test specimens were evaluated in a simultaneous test program. During Phase III, now in progress, both steels will be evaluated for rolling contact fatigue; single tooth bending tests have been completed. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6084.

Improved Manufacturing Techniques For Infrared Suppression Aircraft Components. Infrared suppression components are designed to reduce infrared radiation from both the turbine jet exhaust plume and the surrounding hot metal. The purpose of this project is to reduce the manufacturing costs to produce these metal components for the OV-1 aircraft. Corpus Christi Army Depot is giving this project high priority. They are trying to develop a more economical process with tools to form, shape, slit and cut thin sheets of super alloy A286. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Modification of N/C Language For Automated Tape Layup Systems. In work at Illinois Institute of Technology, numerical control language has been modified in order to preprogram an automated tape layup machine. The preprogramming capability makes it possible to develop an N/C tape for the production of a component without using a digitizing system. The elimination of the digitizing requirement reduces the lead time for N/C tape preparation. The system developed during the project could be used as a basis for future development work on other layup machines. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

Cost Effective Manufacturing Methods For Improved, High-Performance Helicopter Gears. This program is concerned with ausrolling, in combination with improved nondestructive evaluation methods to provide a means to optimize quality, reliability, and cost of high-performance helicopter gears. This program is being conducted in two phases. Phase I provides for improved processing methods for manufacture of high-performance, high-quality gear materials. The work will incorporate advanced manufacturing methods such as ausrolling and would center on producing gears of VASCO X-2 and 9310 steels. Phase II provides for improved finishing via cold rolling of gears. Results of the program will be consolidated into a GEAR Producibility and Technical Data Package (Guide) for high-performance gears. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Fiber-Reinforced Plastic Helicopter Tail Rotor Assembly. Pultrusion technology for manufacturing reliable and cost effective composite helicopter tail rotor assemblies is being developed. The process will replace the current hand layup fabrication procedures. The development of pultrusion manufacturing technology will provide advanced helicopter tail rotor assemblies with improved performance characteristics and operational life to be used efficiently and cost effectively on Army helicopters. The proposed tail rotor blade is different from current inventory tail rotors in that a composite material, flex-beam concept is being utilized. Pultrusion fabrication is a low-cost, automated process, which lends itself well to fabrication of structures that consist primarily of continuous, unidirectional fibers, such as flex-beam tail rotor spars. Principal investigator is Danny Good, Applied Technology Laboratory, Ft. Eustis, Va. Project work is being accomplished by Sikorsky Aircraft. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

DOUGLAS T. ROSS is President of SofTech, Inc. of Waltham, Massachusetts, a company specializing in software technology products and services. Prior to founding SofTech in July, 1969, Mr. Ross was Head of the Computer Applications Group of the M.I.T. Electronic Systems Laboratory for seventeen years. While at M.I.T., Mr. Ross and his group were most noted as the originators of the APT (Automatically Programmed Tool) system for numerically controlled machine tools, developed in 1956–1959, and as the originators of the AED (Automated Engineering Design) approach to software technology developed in 1959–1969 as part of the M.I.T. Computer Aided Design Project. The APT Language (along with Algol, Fortran, and Cobol) is now being standardized worldwide by the International Standards Organization (ISO) as well as in America (through USASI); the AED-0 Language is obtaining growing acceptance for machine independent system programming. Since the early 1950's, Mr. Ross and his group also have been leaders in the field of online computer graphics and interactive languages. Mr. Ross is the originator of the plex theory of problem modeling which provides a common foundation for all of these developments. Mr. Ross received the degree of AB Cum Laude in Mathematics from Oberlin College in 1951, and the SM degree without course specification from M.I.T. in 1954. He has completed the course requirements for the degree of Ph.D. in Mathematics at M.I.T.

INYONG HAM, Professor of Industrial Engineering at Pennsylvania State University, was educated at Seoul National University, the University of Nebraska, and the University of Wisconsin. Dr. Ham has worked in various fields of manufacturing and production not only as an educator and researcher, but also as a consultant on many assignments in the United States as well as in other countries. His special fields of interest are manufacturing processes, tool design, cutting tool evaluation, machinability evaluation, optimization of manufacturing operations, and applications of Group Technology. During the period of 1960–62, Dr. Ham was, successively, Director of Industry and Assistant Minister in Charge of Industry, Power and Mining, Ministry of Commerce and Industry, Republic of Korea. Dr. Ham participated in the formation of the APO (Asian Productivity Organization), and served as the R.O.K. Director of the governing body of the APO. He has conducted many seminars, workshops, and lectures for professional personnel in industry on various areas of manufacturing in the U.S. and in Hong Kong, India, Indonesia, Israel, Japan, Korea, the Philippines, Pakistan, South Vietnam, Sri Lanka, Thailand, and Mexico. He has been a consultant for many U.S. companies as well as international organizations such as APO and UNIDO.

Group Technology: Remedy For Manufacturing Ills

Higher Productivity, Greater Efficiency

With our steadily advancing technology, it's easy to assume that our manufacturing processes are highly productive and efficient—healthy specimens, indeed. After all, when we consider that manufacturing accounts for about 30 percent of our gross national product, we feel it has be be that way.

But it just isn't true. Efficiency is not the rule in manufacturing. Worse, the trend is toward growing inefficiency. Manufacturing has some real ailments, as pointed out in the GAO report of 1976 on manufacturing in the United States. The problems are particularly apparent in batch type metalworking operations—the type of manufacturing that will predominate in the future.

In a typical metalworking shop, parts are actually on machines for only about five percent of the total production time. The other fifty-seven minutes of each hour are spent moving parts and waiting for parts. That isn't all. Only about 30 percent of the time on the machines (or 1.5 percent of total production time) actually goes to machining materials. That's a little less than 1 minute an hour. Figure 1 illustrates this allocation of production time. So actual machining costs often are an insignificant fraction of total costs.

Our cost problems do not lie in the production process itself. We find them in such areas as product design, tool design, tooling setup, production scheduling, labor and equipment utilization, and in process inventories. A major advantage of mass production

is that it keeps such costs down. But this is not so with the batch type operations that loom so large in the future. The more separate parts we deal with in short run operations, the more significant these types of costs become.

Trend Is Toward More Batch Operations

As indicated above, there is a trend toward increasing use of batch type operations in manufacturing. Thus, the current inefficiency of such manufacturing becomes even more significant. At present, about 25 percent of all industrial parts in the United States are produced on a small lot basis. Thoughtful forecasts show this proportion leaping to 75 percent over the next 10 years.

Furthermore, about 75 percent of all U.S. metalworking production involves lots of less than fifty pieces—not the mass production we normally link with modern manufacturing. With the metalworking industry employing about 40 percent of U.S. manufacturing manpower and expending about $50 billion annually, the penalty we are paying for inefficiency is clear.

Group Technology Provides An Answer

Thus, we see a critical need for cost improvement in manufacturing—a need that will become more pronounced with time. Because of this need, attention is turning toward a manufacturing system that meets the problems of batch type operations—a system called group technology.

This approach groups parts either by similar shape, size, and material or by manufacturing process requirements. A coding system is normally used to classify parts and form the groups. When like groups are formed, similar design criteria and technological operations can be applied to each group. Grouping by shape and size is particularly useful in effecting design and engineering improvements. Groups formed by processing considerations are most likely to bring about manufacturing improvements.

The Bottom Line: Reduced Costs

Specifically, improvements might include more effective designs, less stock and fewer purchases, simplified production planning and control, reduced tooling and setup times, flow line production by machine groups, reduced process inventories, faster throughput, reduced numerical control programming, and more efficient use of numerical control machines. All of these improvements mean reduced costs; Figure 2 portrays these cost reductions graphically.

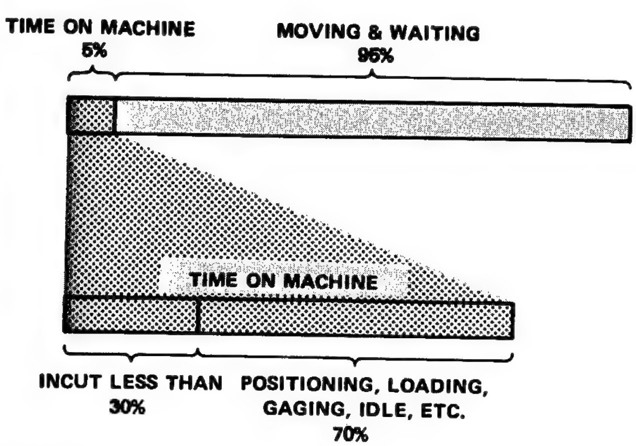


Figure 1

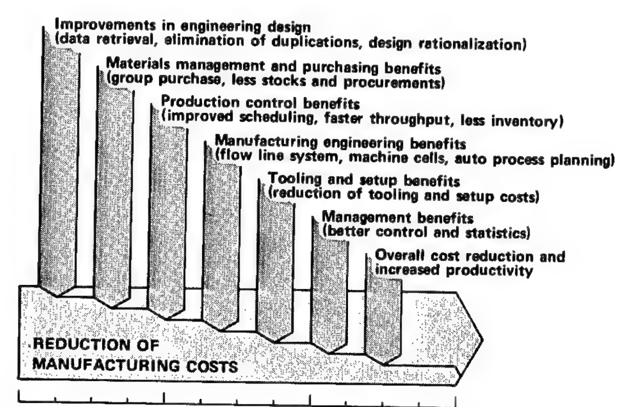


Figure 2

An Old Concept Now Recognized

Group technology is not a new concept, but its importance in meeting current problems is just beginning to be recognized. In Europe and Japan, group technology has taken many forms and been applied in varying degrees, primarily since World War II. Interest in the system broadened considerably during the 1950's and 1960's. During that period, many coding systems were developed and many group tooling practices reported. As knowledge of its concepts and advantages spreads, so does its use.

In this country, manufacturers have applied the basic concept of group technology for many years as a part of "good engineering practice" and "scientific management". For example, F. W. Taylor developed a coding system at the start of this centruy that was used in the manufacturing industry. However, group technology has not been formally recognized nor applied as a systematic approach to small lot production. There are very few published studies, data, or case histories available when compared with the European and Japanese literature.

The Key To Multiple Advantages

Now, the incentives to increase productivity and efficiency, together with the trend toward greater use of batch type operations, are causing many industries to formally recognize group technology as a vital, systematic approach to greater productivity. Further impetus comes from the increasing use of costly machine tools and machining centers. Closer scheduling and control is needed to improve their efficiency. Group technology is also a key to implementing computer aided manufacturing, another important step in improving efficiency.

Two 1973 forecasts of production technology advances emphasize the future importance of group technology. Both the University of Michigan and the International Institute for Production Engineering Research (CIRP) predicted extensive use of group technology in the coming decades. The University of Michigan study predicted more than 50 percent of industry will use group technology by 1988. The CIRP study was even more optimistic, predicting 70 percent utilization by 1990.

What Is Group Technology?

All of this tells us that group technology has an important role to play in increasing manufacturing productivity and that its ability to fill this role is fast gaining recognition. Now let's look a little more closely at just what group technology is, why it has come about, and how it operates.

Group technology is a method of easing some of the problems associated with short run job shop work. The typical shop encounters a great variety of jobs, each with a small number of parts. As a result, these shops often spend more time on setup than on any other activity.

Furthermore, the shop is usually laid out on the basis of processes or functions. There is no interrelationship between groups of equipment with different functions. Each job follows a different and confusing path through the shop. The flow is ragged, production scheduling difficult—often reduced to grabbing the first available machine—and material handling needs are uncertain. Checking the status of a part in process can be an almost impossible task.

Parts Grouped By Machine

Group technology overcomes these problems by grouping all parts requiring similar machines and tooling so that they are processed in sequence. This increases the number of parts run on each setup and cuts setup time sharply. Machines are grouped for similar jobs, allowing better scheduling and control, improving material handling, and boosting morale. Very significant cost reductions are realized.

In applying group technology, we form part "families" by identifying the shape and manufacturing requirements of each part. A functional description of parts is not normally satisfactory for this purpose because parts having similar or identical shape features can carry widely varying functional descriptions.

As noted, part shape and manufacturing requirements are the basic factors considered in grouping parts, but there may be other factors in any particular scheme. Factors that may be involved in defining a family include

- The basic shape of the parts
- The maximum and minimum size of the parts
- Material or materials used for the parts
- Initial form or forms for the parts and the methods of holding them for working
- The tool type and number needed to produce the parts
- The type and size of machines required to produce the parts.

From these parameters, the profile of a part family is constructed. This profile can then be used to accept or reject new parts for the family.

A Key to Effective Group Technology

The key to group technology is a classification and coding system that identifies the parameters for each part and assigns a specific symbol to each. Classification and coding is not the only way to form part families—but it appears to be the best. Another method is a simple visual search of the inventory—eyeballing parts into appropriate groups. Obviously, there are many shortcomings to this approach.

A second method is production flow analysis—a scrutiny of operation sequence and routing of parts. Disadvantages of this method lie in its reliance on existing production data and routing methods and the problems of maintaining and sorting production data manually.

An effective coding and classification system allows examination of all active parts. Part groups can be formed regardless of the origin or use of the parts. Major benefits of an effective classification and coding system are listed in the accompanying box.

How Group Technology Operates

Regardless of the technique used, once groups or families are formed, we know the quantities of each part required over a given period, the allowed machining and setup time, and the actual manufacturing processes used with each part. From this, we can easily calculate total manufacturing times and quantities required in order to form appropriate machine groups and assess machine group loads for each family. If a machine group is not economically loaded, the family parameters of shape, size, and material can be logically extended until a satisfactory load is established.

Finally, each part in a family is examined to determine its tooling requirements. Thus, a group of machines can be brought together that can manufacture the complete part family using the same tooling with auxiliary adapters as needed.

Classification and Coding

There are a number of approaches to the use of a classification and coding system in forming part families—each with its own particular advantages and disadvantages. A future article in the ManTech Journal will consider coding systems in detail. For purposes of introducing the reader to group technology (the major objective of this article), we summarize some of the important considerations. In three basic approaches to classification and coding, part families are formed from

- Parts being produced within a given time period
- One of the company's products
- The company's complete range of products.

There are many varieties of classification and coding systems in use around the world. The coding system used in a specific application should be specific to user needs,

adaptable to future change, and adaptable to computer processing. It also must be useful to all concerned departments within a company—e.g., design/engineering, planning/control, manufacturing/tooling, and management. A company can devise its own classification and coding system or adapt a commercially available system to its needs.

The coding system itself will use alphanumeric characters with certain assigned meanings. The number and meaning of character positions will depend on the purpose of the code. Essentially, there are three types of codes:

- Hierarchic, in which successive characters are dependent on meaning
- Discrete, in which they are independent of meaning
- Combined, in which dependency is mixed.

With this general background, let us consider briefly how group technology may be applied in various phases of manufacturing operations.

Machine Grouping

In group technology, machines are laid out to perform all required operations for a family of parts or a series of families in the most efficient way. The machines are arrayed in a flow line to minimize transportation and waiting time, thus reducing in-process inventory. A shop will contain as many machine groups as needed to accommodate the part families identified for that company. A typical group layout is shown in Figure 3.

Since the load for each machine in a group is easily calculated from data on the part family or families involved, an effort is made to maximize machine utilization by

- Extending basic part families by adding parts of a similar type or merging two or more subfamilies
- Machining two or more part families on the same machine group.

Group machine layouts offer many advantages in increased productivity and efficiency. At the same time, they introduce problems such as balance of labor and machine utilization. Solutions to these problems, however, are really just a part of establishing effective group technology through a computerized approach.

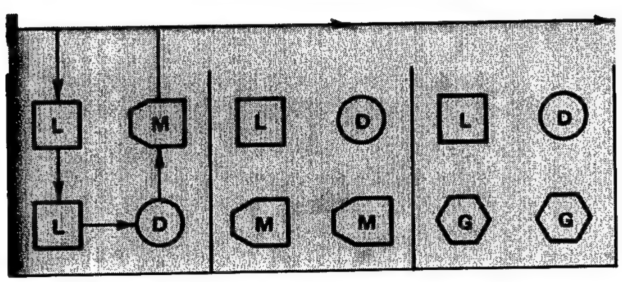


Figure 3

Fixtures and Tooling

Ideally, all the parts in a family will be run with a single fixture and setup for a particular operation. This provides maximum efficiency. For example, a family of fifteen parts required just one master jig and eight auxiliary adapters to drill a different number of holes of different sizes at different locations in each part. Such consolidation allows tremendous savings in tooling costs, as well as savings in both setup and downtime. Where different tooling setups are required, tools can be preset and given a code number that corresponds to the family. Then tooling setup is simply a matter of selecting and installing the proper preset tooling and occassionally changing a tool. Again, downtime is reduced markedly.

Production Control and Scheduling

Formation of machine groups greatly simplifies production scheduling. Rather than scheduling the shop as a whole and rarely getting a schedule that is satisfactory or even practical, each small group of machines is handled individually. Within the machine group, scheduling is merely a matter of sequencing and loading.

As noted above, proper scheduling is actually an integral part of an effective group technology system and, as such, will be handled by a computer program. Proper group scheduling, with reduced setup and transportation time, provides the greatest benefits of the group technology system. Reduced total production time is another obvious benefit. As processing becomes more efficient, in-process inventories can be reduced by about 50 percent, meanwhile allowing shorter delivery times with more certainty of meeting the delivery dates.

Numerical Control

Numerically controlled machine tools offer many advantages. Unfortunately, these advantages are often outweighed by problems and costs of production planning, tooling, low utilization, and long setup times. Consequently, this type of automatic equipment has generally been too costly for batch type operations.

Proper application of group technology, however, will reduce such costs and enhance the advantages of NC tools. The use of such equipment then becomes both economically feasible and very attractive. Because group technology and numerical control claim many of the same advantages, they are mutually supporting and can even be self improving. For example, the adaptability of NC machines in conjunction with group technology reduces setup time even more than previously described. Furthermore, the capacity of many of these machines is sufficient to sharply reduce the number of machines required in a shop. Finally, the continuous feeding of workpieces that results from group technology improves the loading efficiency of NC machines, thus reducing direct manufacturing costs and minimizing tool variety.

One specific application of group technology is a software development program called part family programming. This system groups common or similar program elements into a single master computer program. The master program, or preprocessor, becomes a permanent base from which an NC tape can be prepared for any part in a family. This increases productivity by saving programming time, manpower, and tape proveout time. It also reduces lead time and tool inventory, simplifies maintenance, and reduces the number of computer reruns.

Computer Aided Manufacturing

Computerized process planning is essential to CAD/CAM implementation, serving as the basis for a rational and logical approach to component design and manufacturing efficiency. The decision making framework in this planning approach is based on algorithms or logic flow diagrams for each decision making stage.

Of particular importance are procedures to retrieve information on part design specifications, tooling requirements, and processing conditions and capabilities. This is where group technology plays a key role.

Computer aided process planning can be accomplished either by retrieving available data or by a generative process. In either case, the part family is an essential element in planning, and a suitable classification and coding system is vital.

Through classification and coding and the development of part families, the planner can break complex manufacturing problems into small controllable segments. Thus, by rationalizing and developing shape and process standards for part families, he or she can form the basis for future computer generated process planning.

An Ever Changing Process

Group technology is a dynamic process and its role is broadening as more manufacturers become aware of its capabilities and advantages. Further innovations can be expected in the system and its use in boosting productivity and implementing computer aided manufacturing.

In this brief article, we have tried to acquaint you with the capabilities and advantages of group technology. The key lies in an effective classification and coding system. Future articles in this series will provide details on the needs and major parameters of these systems, compare currently available systems, and outline recommendations for selecting and developing the right system to meet your needs.

- Formation of groups of parts (part families) and machine groups
- Quick retrieval of designs, drawings, and production plans
- Design rationalization and reduction of design costs
- Reliable workpiece statistics
- Accurate estimation of machine tool requirements, rationalized machine loading, and optimized capital expenditure
- Rationalization of tooling setup and reduction of setup time and overall production time
- Rationalization and improvement of tool design and reduction of tool design and fabrication times and costs
- Rationalization of production planning procedures and scheduling
- Accurate cost accounting and cost estimation
- Better utilization of machine tools, workholding devices, and manpower
- Improvement in numerical control (NC) programming and effective uses of NC machines.

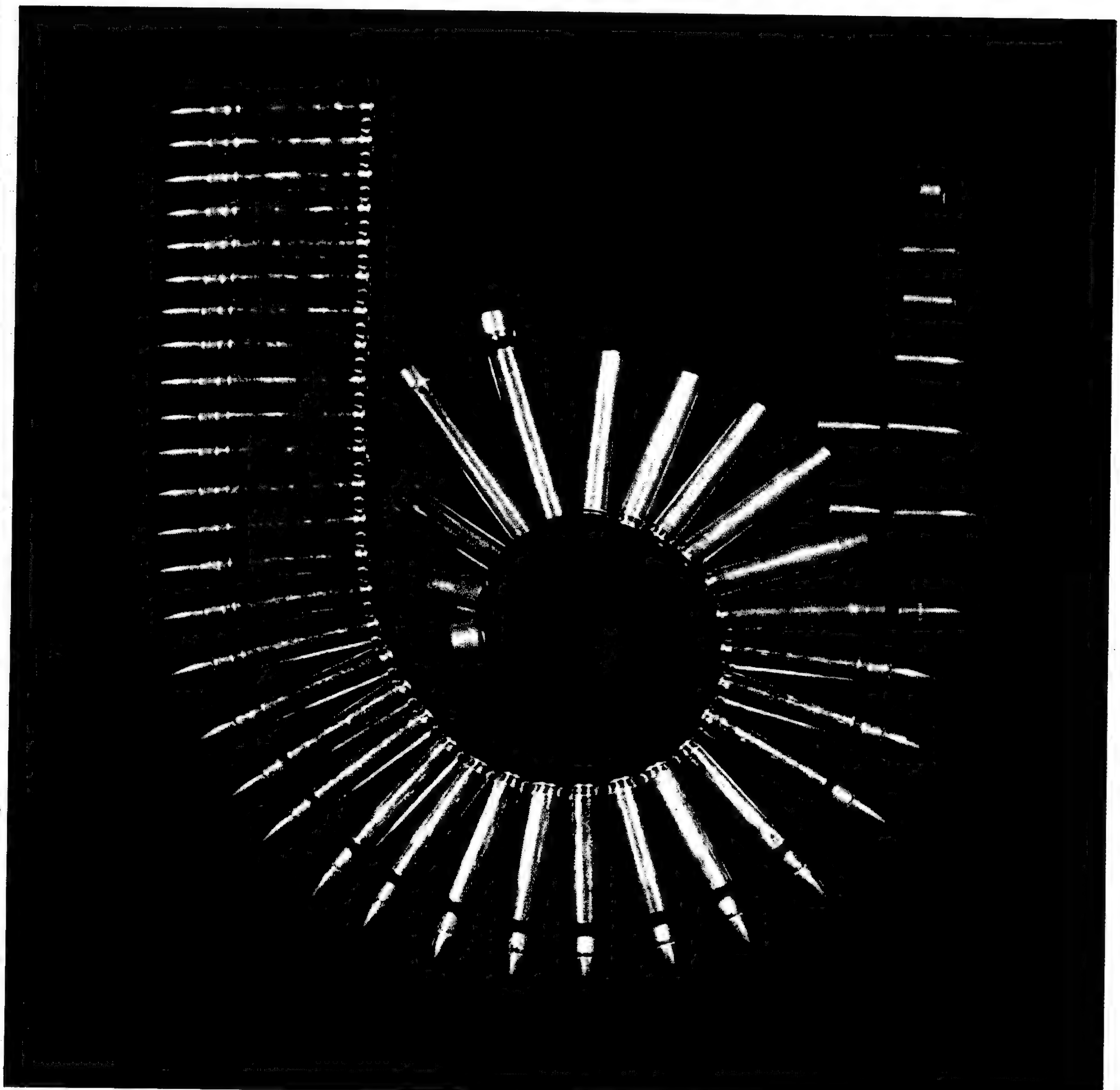
Editor's note: This article on Group Technology is based partially on the U.S. Air Force ICAM report to which Dr. Ham and Mr. Ross contributed. The report was furnished the Army by the courtesy of Captain Dan L. Shunk, ICAM Project Manager, Air Force Materials Laboratory, Wright-Patterson AFB, (513) 255-2562.

USArmy

ManTechJournal

Proven Tests in Time to Help

Volume 3/Number 2/1978



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US Army ManTech Journal

Contents

ABOUT THE COVER:

The U.S. Army's Small Caliber Ammunition Modernization Program (SCAMP) is typified in this imaginative photograph by Battelle staff photographer Bill Weider. The individual pieces exemplify the actual production steps in the fabrication of the copper bullets and brass cartridges, including several anneals following forming. All steps are performed automatically at a rate of 20 units per second on rotary turret stations, as detailed in the article "21st Century Production Techniques Today" featured in this issue. The production system represents the most modern of approaches to quality assurance, with complete product testing conducted automatically during the high-speed fabrication sequence.

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Comments by the Editor


DR. JOHN J. BURKE

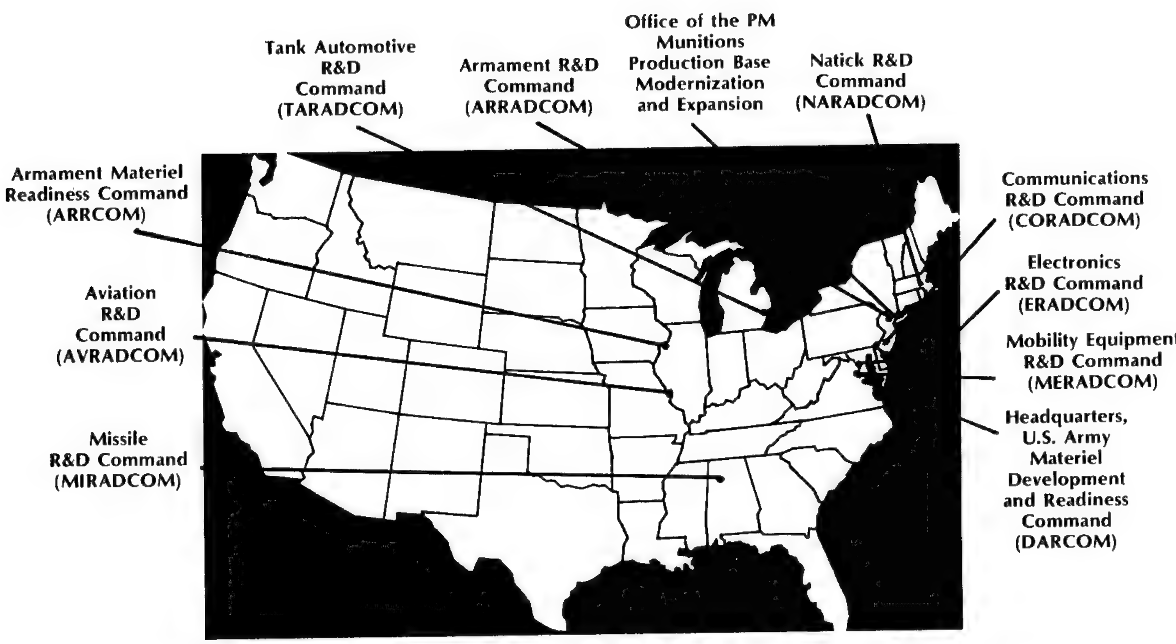
No facet of modern manufacturing technology is changing so rapidly and has so dramatic an impact on our methods of fabrication than that of materials testing and product assurance. A virtual revolution in quality control and comprehensive inspection is occurring because of our new sophisticated nondestructive testing techniques and automated quality control procedures. Articles in this issue of the ManTech Journal highlight some of these fantastic new developments—developments which are completely restructuring the thinking of manufacturing engineers throughout the world. A beautiful example is presented in the pair of articles on the SCAMP (Small Caliber Ammunition Modernization Program) project of the U.S. Army. The production control and use of the most advanced quality control systems described in these two articles exemplify the direction being taken by Army planners as obsolete plants are completely renovated and the most sophisticated production control systems in the world are put on stream. Not only will increased efficiency literally slash the cost of producing many of our military items, but the nation's security will be immensely improved by the prospect of rapid mobilization capability. And these new systems of production can easily be put to use in the commercial sector to benefit our civilian population. In fact (as in the case with the SCAMP project), many of the systems put into effect originally have been borrowed from the civilian sector and then highly refined.

Computers, electronic devices, X-rays, lasers, ultrasonics—all these will continue to play a major role in our lives and standard of living in the United States. And the foresighted thinking of Army managers who have taken the initiative in establishing programs to implement these new production systems will have a powerful impact upon the welfare of that standard of living we now enjoy. But in the immediate future, one can see vast improvements in our quality of life in the United States, in no small way an effect of these Army production renovation programs. Not only bullets, tanks, guns, and helicopters can be produced by these new systems, but cars with new structural concepts will be produced in a manner that most nations will not enjoy until the next century. And these products will comprise the most reliable, safe, economical, and long lasting spectrum of goods seen in the history of the world. Such will be the effect of

much of the development work that the Army has funded in the area of manufacturing technology.

The next issue of the ManTech Journal will emphasize the Army's efforts in casting, with additional material submitted by several of our leading industrial firms. Some of the advances already made in this rapidly changing field are profoundly influencing some of our traditional methods of fabrication. New materials properties are as dramatic a side effect of some of these developments as are the efficiencies resulting from them. Slashing of production costs is only one side of the coin in the Army's manufacturing technology efforts—greater security for military personnel from a safety and reliability standpoint is also a prime objective. Some of the developments discussed in the articles of this next issue of the ManTech Journal address these factors. A representative of one of the Army's most important suppliers was heard to make the statement at the MTAG meeting in Dallas two years ago that "Probably the most difficult obstacle our firm faces in the current production capability posture of this nation is finding subcontractors who can furnish us with quality castings at a price that will allow us to market a competitive product both costwise and qualitywise." We think some of the articles in this forthcoming issue will provide new insights into the problems being referred to by this engineer and also will provide new means for dealing with these problems.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



SEYMOUR J. LORBER is Director of Quality Assurance at the U.S. Army Materiel Development and Readiness Command. He came to DARCOM in 1962 from the Industrial Division, office of the Chief of Ordnance, where he served as Chief of the Quality Control Office. Mr. Lorber has a B.S. in Industrial Engineering from the Illinois Institute of Technology and a M.S. in Engineering Science from Stanford. He is a Fellow of the American Society for Quality Control and a member of the Society of America's Value Engineers, the American Defense Preparedness Association, and the Society of Logistics Engineers.

MTT Vital To New Equipment

NDT When It Counts Most

Nondestructive testing procedures adapted for new manufacturing technology programs at their inception bring new military items into service in remarkably less time.

The Army's Research and Development is directed toward introducing more effective materiel into the equipment inventory. From weapons and munitions to aircraft, these efforts have been marked with increased effectiveness—much of which has resulted from the use of new materials or new treatments of materials. For these materials to effectively and safely realize their full potential requires precision manufacture. This poses a continuing challenge to the Army's Quality Assurance Program. How do we make sure that such items will survive all the environments to which they are subjected and still be ready to operate as intended when we need them some years later? How can we be sure of this integrity without destroying the item as we inspect it?

MTT Program Implemented

To answer such questions, the Materials Testing Technology (MTT) program was instituted emphasizing nondestructive tests. This effort is a necessary adjunct to our equipment development program. Its objective is to define procedures that will assure us of product quality and long term integrity from the beginning with initial production of new equipment. In program after program—fragmenting artillery shells, howitzer energy penetrators, composite materials in everything from helmets to helicopter rotor blades—the output of the MTT program has been identified as the keystone to successful quality assurance.

To highlight the concern that quality assurance procedures be well established at the time of initial production of new equipment, Quality Readiness Reviews (QRR) were required for some critical items. These QRR's include a review of the inspection procedures and equipment necessary from the raw material stage to final assembly. In those QRR's carried out to date, the acceptance of the new equipment has hinged on the procedures and inspection equipment that have evolved as a result of the MTT program.

Lead Time Critical

The importance of the program cannot be overemphasized. Product quality assurance depends on its full support. MTT must be brought into development programs in the earliest stages so that the introduction of new equipment into service will not be delayed by tardy development of inspection procedures. DARCOM looks to the Army Materials and Mechanics Research Center (AMMRC) to manage this program. However, everyone participating in the various weapons system development programs is called upon to make certain that AMMRC's perspective is brought into the programs quickly. Thus, the Materials Testing Technology program can provide the necessary test methods, procedures, and equipment when they are needed.

NORBERT H. FAHEY, Chief of the Materials Testing Technology Division, has held a variety of positions at the Army Materials and Mechanics Research Center during the past 25 years; his expertise is in the area of inspection and testing. Prior to his current position, Mr. Fahey served as Deputy Chief of the Materials Testing Laboratory and as Chief of the Quality Assurance Division. He presently is responsible for coordinating and supervising the DARCOM Materials Testing Technology Program. Mr. Fahey serves as Chairman of both the DARCOM Materials Advisory Group on Test and Evaluation Methods, and the DARCOM Materials Testing Technology Committee; he is an active member of the Test and Inspection Subcommittee of the DoD Manufacturing Technology Advisory Group, and is the Army member of the Product Assurance Division of the American Defense Preparedness Association. He also is a member of ASTM.

AMMRC Supports Wide Variety of Projects

Formalized MTT Program Implemented

Many of the programs discussed in this issue of the ManTech Journal are an outgrowth of the Army's Materials Testing Technology program, which is managed by the Army Materials and Mechanics Research Center. As you read these articles, you might ask, "What is the purpose of hte MTT program, how does it operate, and where is it headed?"—Let's try to answer these questions.

The MTT program had its start in the mid 1960's at what was then the Watertown Arsenal Laboratories (forerunner of AMMRC). Important testing technology was coming out of research and development activities at Watertown; however, most of it was dying on the vine. Personnel there were concerned that these developments, particularly in the area of nondestructive testing (NDT), were not being advanced for use as inspection tools in product manufacture. For example, the first industrial use of X-rays in NDT of metals was at Watertown, but the process was not finding other applications.

Therefore, with support of the Director of Quality Assurance, the MTT program was instituted at Watertown in 1964 to support NDT efforts in the armaments area. The idea was to support the establishment and advancement of new test procedures and equipment. The MTT scope has expanded through the years and now includes mechanical, chemical, and nondestructive testing techniques for all DARCOM (U.S. Army Materiel Development and Readiness Command) items in, or scheduled for, production. As shown in Figure 1, which illustrates recent program funding, the MTT program now supports efforts at all of the major subordinate commands.

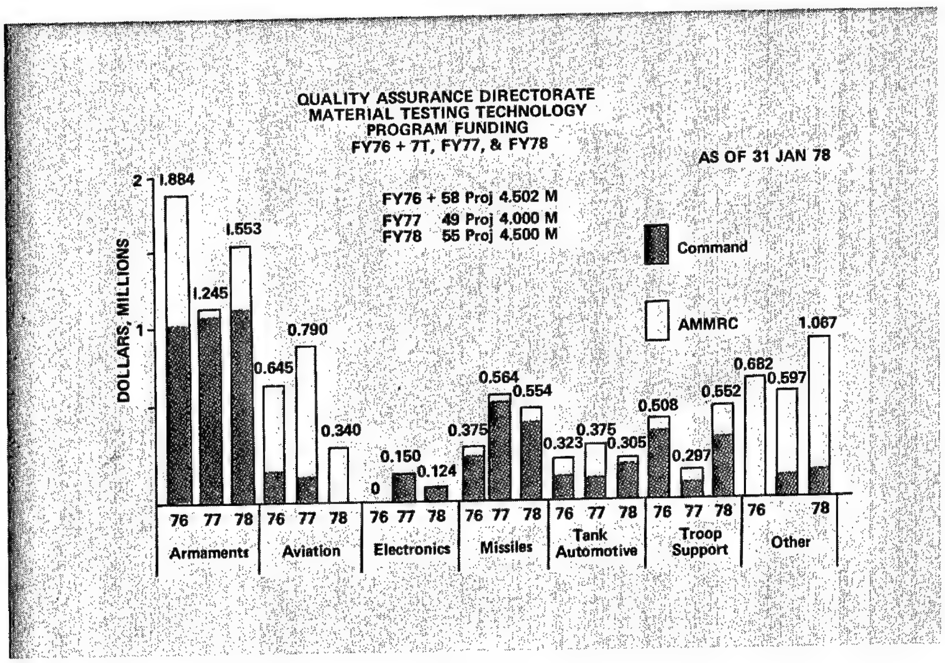


Figure 1

The projects and problems submitted are reviewed by members of a technical working group comprised of experts from within DARCOM in the areas of mechanical, chemical, and nondestructive testing. These experts review the project proposals in relation to such factors as technical adequacy of the proposed approach, cost, and return on investment. When reviewing suggested problem areas, they can, and do, recommend proposed solutions. They also are familiar with both Government and industrial capabilities in their respective areas and often can recommend specific contacts.

Goals Clearly Defined

The MTT program objective is described in AMCR 702-14 as "the timely establishment or improvement of mechanical, chemical, and/or nondestructive testing methods, procedures, or prototype equipment used in the inspection of DARCOM materiel being procured, used, or stored and the assurance of the ability to produce, reduce lead time, insure economic availability of end items, reduce costs, increase efficiency, provide reliability, and/or enhance safety." If that's not too clear, specific program goals are to

- Establish new test methods and prototype test equipment
- Improve existing test methods and prototype equipment
- Establish personnel qualification standards
- Furnish technical assistance
- Disseminate technical information.

Project Review Helpful

Input for the MTT program comes in two forms. First, other commands may submit proposed projects to develop a solution to an identified inspection requirement for one of their components or items. Second, a command or a project or product manager may submit a request for assistance with an inspection problem or requirement.

DARCOM Approval Obtained

Upon approval of individual projects and establishment of priorities for them, a master program is submitted to DARCOM for approval. When this program is approved and funds are received, AMMRC then funds the respective stations where the work will be performed. Approximately 60 to 70 percent of the total MTT program involves NDT efforts and these efforts account for most of the NDT work done within DARCOM.

All tasks are monitored by Materials Testing Technology Division personnel at AMMRC. Final reports, as well as semiannual reports of accomplishments, are submitted on each program. AMMRC liaison personnel make at least two visits per year to each station to monitor progress.

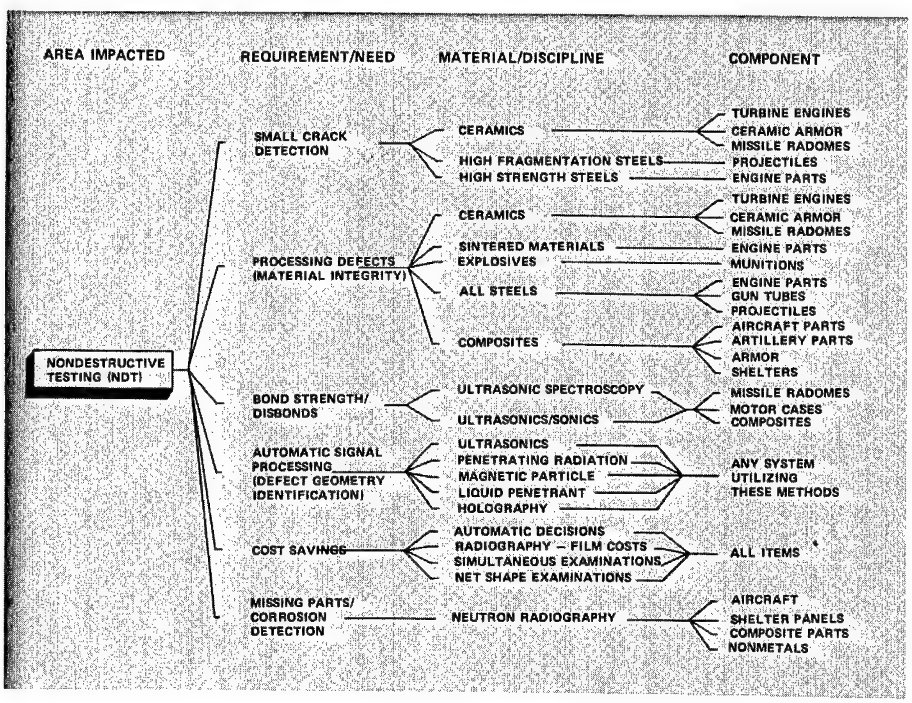


Figure 2

Comprehensive Program Implemented

The MTT program emphasis for FY 77-81 in the areas of nondestructive, mechanical, and chemical testing is shown in the Spidercharts in Figures 2 and 3. The MTT program can be useful to any command or project manager who is trying to

- Ascertain material condition
- Monitor manufacturing processes
- Measure critical defects
- Assess remaining service life
- Replace human judgement in accept/reject situations
- Substitute for costly proof/life testing.

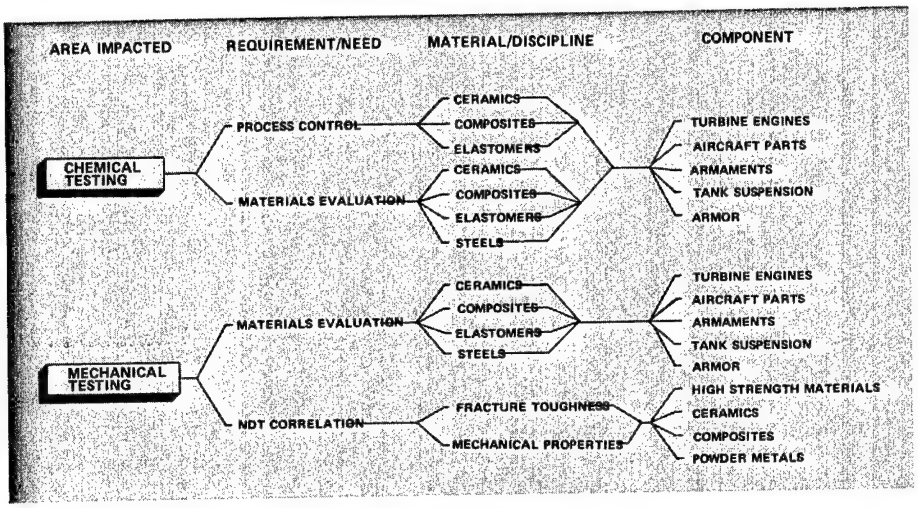


Figure 3

Information relative to the MTT program operation can be obtained by contacting the author at the Army Materials and Mechanics Research Center, ATTN: DRXMR-M, Watertown, MA 02172, Telephone: 617/923-3466 or AUTOVON: 955-3466.

Medical Technology Used

Test Methods Cover Wide Spectrum

With the rush to automate Army materiel production, inspection technology is being pressed to keep pace. As a result, some exciting, eye opening things are taking place in testing technology at the Army Materials and Mechanics Research Center (AMMRC). For example, inspection of rotating bands that once took several minutes can now be done in about 5 seconds utilizing advanced ultrasonic techniques!

Dramatic? You bet! But it's only one of many recent, startling developments in materials testing at AMMRC. Through their Materials Testing Technology (MTT) program, AMMRC is improving testing capabilities while reducing testing costs for a diverse range of materiel using a wide variety of testing techniques. Operating at the forefront of mechanical, chemical, and nondestructive testing (NDT) technology, AMMRC has developed and implemented techniques to keep pace with the manufacturing advances.

GEORGE DARCY is Chief of the Nondestructive Testing Industrial Applications Branch at the Army Materials and Mechanics Research Center, Watertown, Massachusetts. After graduation from Harvard University in Engineering Science and Applied Physics, he worked in electronic design for The Navy Department and General Communications Company. His career in nondestructive testing began in 1950 at the Watertown Arsenal Laboratories, where he was involved with artillery shell and gun barrel NDT development. He had an interim assignment as Chief of the Research Program Office at the Center in the 1960's while he maintained an appointment as U.S. National Leader on an international defense exchange program on NDT technology. He has served on various national boards on NDT technology including an appointment as Army Liaison Member to the recent National Materials Advisory Board study on the Economic and Management Aspects of NDT in Aerospace Manufacturing. He currently is Chairman of the Army Technical Working Subgroup on Nondestructive Testing. Mr. Darcy is a Registered Professional Engineer in Massachusetts and a member of the American Society for Nondestructive Testing and the American Defense Preparedness Association.

The task is not simple. The Army has the widest spectrum of manufacturing and testing needs among the three services. Army production ranges from tanks, trucks, helicopters, small arms, artillery, ammunition, and missiles through communications and electronics equipment to clothing and even packaging of foods. The great diversity of needs is also seen in the testing technologies involved. These include ultrasonics, magnetics, X-ray and N-ray imaging, optics, chromatography, automatic flaw signal interpretation, infrared imaging, and many more. As a matter of fact, a recent national compilation listed 70 different techniques used in nondestructive testing. Most of these 70 are utilized in the manufacture of Army materiel.

The MTT program is geared to increasing test speed, removing the operator from the test loop to avoid fatigue problems, and eliminating subjective interpretation of test results. Another goal is 100 percent sampling for certain critical items that are produced in large quantities. Typically, only a very small percent of such items are sampled. Complete coverage has been highly impractical, if not impossible, using existing testing techniques with built-in time and cost constraints.

Through its MTT work, AMMRC is developing rapid testing techniques that are both practical and economical. A brief discussion of just six programs illustrates the type of progress being made.

Ultrasonics Slash Inspection Time

As already noted, ultrasonic techniques have been developed to drastically reduce inspection time on rotating bands. The method also has been successfully applied to other products, including tank wheels and artillery shells. The system, which has the advantages of high scan speed and fast printout, utilizes technology from the medical field and incorporates other imaging advancements.

In the past, ultrasonic equipment was not competitive with X-ray techniques for nondestructive testing. In the first place, X-ray techniques had the advantage of providing a pictorial image. In addition, ultrasonic problems presented by hand held probes, transducer contact considerations, and difficulties in interpreting oscilloscope indications limited its use. When AMMRC surveyed the medical field, however, they became aware of vast strides in medical ultrasound in the past 15 years and sought to incorporate the improvements in an NDT system.

As a result, AMMRC is employing a medical ultrasonic unit that uses a 64 element transducer. The unit ordinarily produces a B-scan, but has been modified and adapted with a scan converter, expanded television display, and recorder printout. These modifications allow the preparation of both B- and C-scan data. Current activities are directed toward incorporating computer interaction for data processing, signal analysis, and transducer control.

Automatic Inspection of High Explosives

In another program, a cooperative effort involving AMMRC and Armaments Research and Development Command personnel is producing automatic inspection equipment for high explosive shells. The system utilizes tomographic X-ray techniques for automatic decision making, eliminating radiographic film and interpreters. An engineering model of the system, as shown in Figure 1, is now being completed.
An operational system will be built in conjunction with the automated melt-pour process now in development for the Lone Star Ammunition Plant (see ManTech Journal, Vol. 2, No. 2, p. 39).

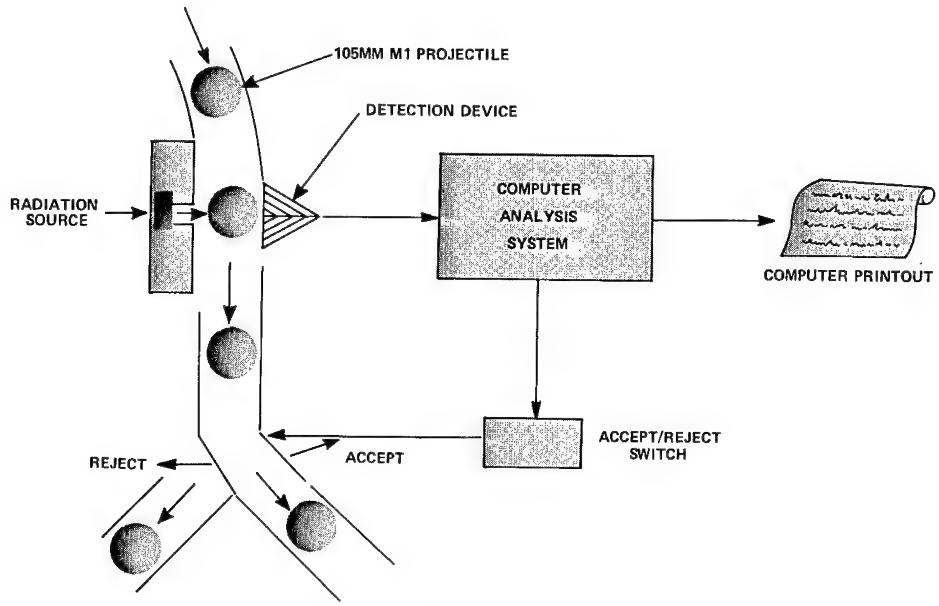


Figure 1

The need for such equipment became obvious as the Army embarked on a program to automate ammunition production. Currently, explosives for 105-mm shells, for example, are poured manually. Present quality assurance practices call for radiographic inspection of only two of every fifty filled shells; these tests are designed to detect voids, bubbles, cracks, and separations from the walls and base.

The modern automated production lines being installed at Lone Star call for 100 percent inspection of shells at a rate of 44 per minute. At full three shift production, this would mean 60,000 inspections per day. This could not be done with conventional X-ray procedures because of the cost of silver base film, the salaries of test operators and film interpreters, and the number of X-ray machines that would be required to match production.

To develop a system that would overcome these shortcomings, a project called AIDECS (Automatic Inspection Device for Explosive Charge in Shell) was launched in 1974. The engineering model that has evolved from that program provides 100 percent inspection of 44 shells per minute. This model requires several more years of engineering and prototype development before it will be installed at Lone Star.

Bearing Inspection Upgraded

Three separate technologies are being utilized in new bearing inspection equipment at Corpus Christi Army Depot's bearing facility. Premature failure of critical aircraft bearings has long been a problem that has caused unwarranted overhaul expenditures. In some cases, such failure has caused the loss of aircraft and personnel. Thus, there was a critical need for nondestructive diagnostic equipment that could detect surface and subsurface defects in both new and used antifriction bearing components used in the Army's helicopter maintenance and overhaul program.

At the request of the Army Aviation Research and Development Command (AVRADCOM), AMMRC undertook a program to fill this need. As a result, Southwest Research Institute has designed and constructed bearing diagnostic equipment that can

inspect on a production basis the wide variety of bearings presently used in Army helicopter jet engines and power trains. This equipment employs three testing technologies:

- Magnetic leakage field techniques for the detection of subsurface defects in new bearing raceways
- The magnetic Barkhausen technique for measurement of variations in residual stress in bearing components
- A dynamic acoustical analysis technique for the detection of service induced damage in used bearings

The completed equipment was installed at Corpus Christi during 1977.

Night Vision Technology Aids Infrared NDT

Utilizing technology developed for night vision devices, AMMRC is expanding infrared capabilities in the NDT area. The Center at Watertown, Massachusetts has been a pioneer in the use of infrared and thermal techniques for nondestructive testing and continues to seek improvements. Current efforts are directed to a highly sophisticated pyroelectric vidicon that will be a major advancement in the state of the art.

Infrared imaging has been widely applied in NDT cases in which it may reveal a subsurface anomaly in terms of a surface thermal pattern. Separations of plies in pneumatic tires, the integrity of rocket motors, vacuum insulated canteens, foamed-in-place insulation in food containers, flexible food package seals, honeycomb structural panels, and microwelds, all have been examined by infrared imaging techniques.

However, infrared camera technology has proven to be a drawback to even wider use. Cameras have been very bulky with a liquid gas cooled, semiconductor point detector and a complex mechanical raster scan system of rotating mirrors producing the image.

Now, new European and U.S. night vision developments have been applied to improve IR imaging for NDT. The night vision developments have led to significant improvements in portability and image definition. These improvements are being exploited in an uncooled imaging system that represents a marked advance in IR application to NDT. It's an all electronic system employing a vidicon imaging tube with a pyroelectric sensitive surface. The new pyroelectric system eliminates the liquid gas cooling problem and the high-speed mechanical scanning system while utilizing comparatively simple designs. The capabilities of this equipment have been demonstrated, and a prototype soon will be delivered by Barnes Engineering Company.

Composite Prepregs Proven Before Use

In a very promising effort that is receiving widespread attention, AMMRC researchers have successfully applied liquid chromatography to analyze composite prepreg material. This effort assumes major significance as fiber reinforced epoxy resin composites are used more in aircraft, surface vehicles, and armaments. These composites are produced from prepreg material—a combination of fibers and an epoxy resin formulation. Their quality is closely tied to the chemical composition of the prepreg material, since the prepreg material is very reactive and its composition changes with age. Thus, analysis just prior to use is essential. Initial AMMRC efforts have used high pressure liquid chromatography equipment to successfully analyze several prepregs.

Figure 2 shows results of composite prepreg analysis using this technique. The graph on the left indicates good prepreg material. Each peak in that graph represents a different constituent. The two prominent peaks represent the epoxy resin monomer and the curing agent, the two major constituents of the prepreg. In the graph on the right, a third major peak has been introduced. In this case, the third peak represents a reaction product, indicating the prepreg has aged beyond its useful life and is unacceptable.

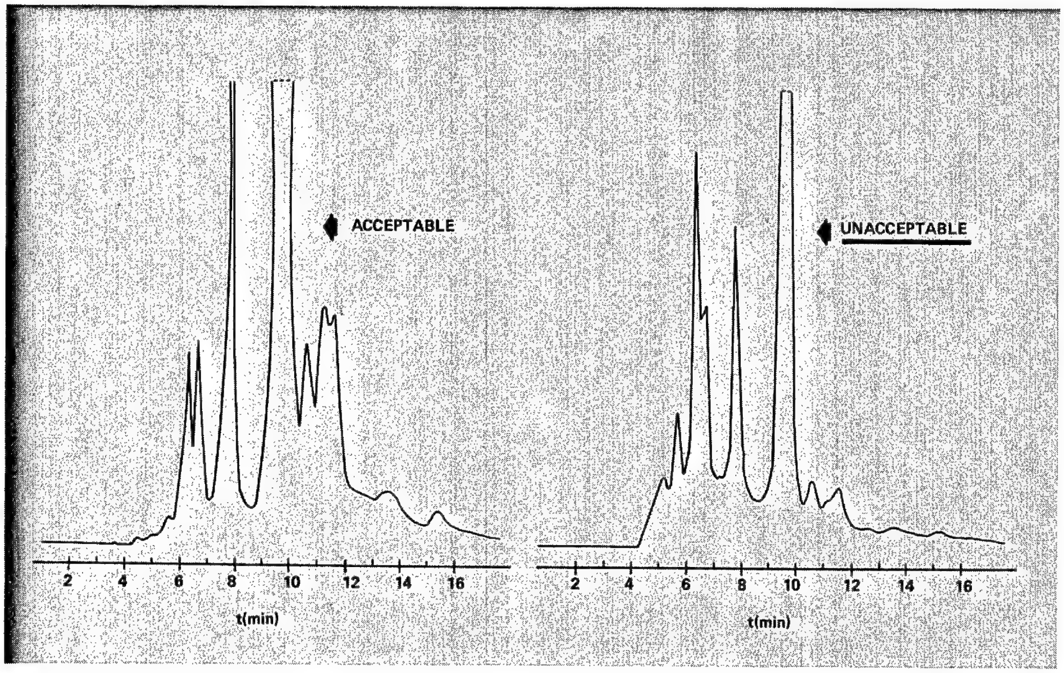


Figure 2

Figure 3

The initial work on this technique has generated a tremendous amount of interest from Government agencies and private industry. Future work will be directed toward establishing generalized testing procedures applicable to all resin prepreg systems. This will allow all material used in fiber epoxy compounds to be characterized for acceptable parameters related to each application and to be analyzed prior to or during each batch use.

Portable Unit Performs Metallographic Analysis

A final example of AMMRC developments in improved testing techniques is a portable metallographic analysis unit. This unit (Figure 3) extends capabilities for field analysis of component failures. Normally, failure analyses in or out of service, as well as evaluation of foreign materiel, are carried out in Army laboratories. However, there are frequent needs for field examinations, and field analysis sometimes is the only alternative. Normally in these cases, trained personnel visit the site to determine the scope of the problem and perform an on-site analysis without benefit of laboratory facilities.

Now, AMMRC's portable metallographic kit will allow failure analysis, material identification, hardness measurement, and structural determination in the field. The kit weighs 100 pounds and measures 2 feet by 2 feet by 16 inches. It is easily transported by one person to an equipment failure site to perform the various metallurgical tests.

Lasers Inspect Gun Tubes

60% Faster, More Reliable

Thanks to recent Material Testing Technology efforts at Watervliet Arsenal, inspection time for cannon barrel bores has been slashed by 60 percent. The newly developed procedures and equipment provide more reliable inspection results and should be adaptable to other related product inspections, including those for pipelines or steel tubing.

These automated techniques center on two cannon inspection systems for use in 105-mm and 155-mm cannon barrel bores. One system (Figure 1) automatically measures and records bore and groove diameters (and their eccentricity)—and also straightness—by means of laser alignment equipment. System use has reduced inspection time by 33 minutes, or nearly 60 percent.

Figure 1

The other system (Figure 2) locates cannon bore cracks, inclusions, and discontinuities by employing an

Figure 2

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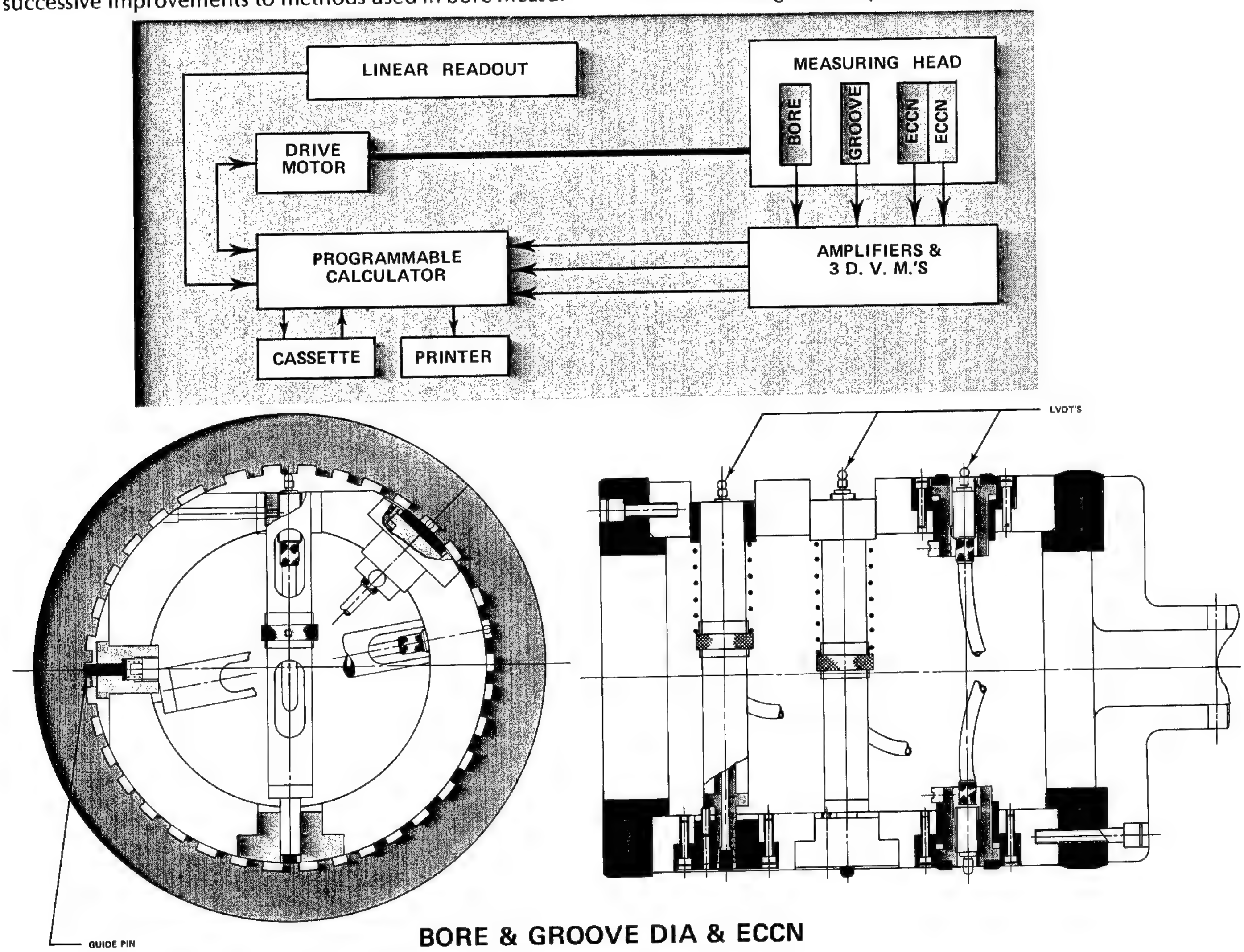
automatic laser scan setup. Inspection time here has been shortened by approximately 50 percent.

Chief objectives at the outset of the MTT effort were to obtain greater accuracy and repeatability in measurements of bore dimensions and straightness and to ensure complete reliability in flaw detection methods. Overriding concerns in pursuing these objectives were installation costs, calibration ease and reliability, time savings, and elimination of human error.

Improvements Made on Previous MTT Programs

Past MTT projects (1968, 1969, 1973) all provided successive improvements to methods used in bore measuring. Early programs, for example, focused on the existing "air gaging" method, in which air sensors and air columns provided the means for taking bore and rifling diameter measurements. Although fairly accurate, the system encountered costly air filter maintenance problems and calibration difficulties and required manual recording and computation of eccentricity measurements. Replacement of air sensors and columns with electronic cartridges and amplifiers, respectively, remedied previous difficulties and not only allowed automatic measurement recording and computation (thereby eliminating chance of human error) but reduced inspection and downtime. As the result of a later MTT program (1973), a second generation electronic bore measuring system was developed which featured a solid state design for improved reliability.



BORE & GROOVE DIA & ECCN

Figure 3

Stemming from a 1972 MTT program, measurement of barrel straightness was also improved with the introduction of a laser inspection system that replaced the earlier method of operator observation through an optical system. The new system eliminated the human fatigue factor and chance of error by providing for automatic detection and recording of straightness deviations. Overall system accuracy was thus improved to a considerable extent.

Efficiency Through Consolidation

Continuing improvements in MTT cannon barrel inspection programs finally culminated in an even more efficient system that was envisioned to consolidate several inspection procedures at one location, utilizing a single data collecting and recording center.

Thus, in 1977, using the experience gained from previous programs, acquisition and installation of the new automatic cannon barrel inspection station was completed and benefits were soon realized.

Total Automation in a Smaller System

Occupying only half the floor space required for the older air gaging equipment, the new system is approximately 30 feet long, 5 feet wide, and 45 inches high. Components include a machine type of base, mobile air bearing support tables upon which adjustable power rollers are mounted, and a flexible power track that advances the measuring heads through the bore. Data storage and retrieval are accomplished through use of a Hewlett-Packard programmable calculator with thermal printer and magnetic type cassette. Linear variable differential transformers in the measuring head provide diameter measurements, and a laser alignment system facilitates barrel straightness checks. For convenience, all readouts and interfaces for the system are located in a rollaround console.

Dimension measurement entails lowering the cannon barrel onto rollers that have been adjusted to align the bore with the measuring heads. The support tables facilitate longitudinal positioning and the rollers are used to orient the barrel radially. Using a hand held control box, the operator "jogs" the measuring head into the bore, loads the appropriate inspection program, and enters the barrel number and date. Pushbuttons are actuated to turn over control to the inspection system, as well as return control to the operator.

To accomplish bore measurement, a guide pin is engaged in the rifling groove, causing the measuring head to rotate as it advances downbore (see Figure 3). As the head reaches the bore's end, it stops, reverses direction, returns to the starting position, and stops. The operator rotates the head 90 degress, returns control to the system, and inspection is repeated with a second "pass" through the barrel.

A reading—i.e., complete set of data—is taken for each "pass". Measurements are recorded at preprogrammed intervals of 5 inches and represent deviations from basic rather than actual sizes. The two readings, which have been formatted and printed by the calculator, are compared, and any dimension not within drawing specifications is flagged with an asterisk to indicate out of tolerance conditions (see Figure 4).

Barrel straightness measurements are performed by changing the measuring heads (by means of a quick dis-

SHOP RECORD — DIAMETERS & LENGTH

TUBE 105 MM M68 — DWG. NO. F8765961 — DATE YR MO DA 780614
SERIAL NO . . . . — SHOP NO 5607 — INSPECTOR . . . .
BORE = 4.134 + .002 — GROOVE = 4.224 + .004 — ECCENTRICITY = .004
BORE DIA AT RECORDED LENGTH — GROOVE DIA AT -1 — ECCENTRICITY AT +1

	POSN 1 (0 DEG)			POSN 2 (90 DEG)		
LENGTH	BORE	GROOVE	ECCN	BORE	GROOVE	ECCN
210	.0014	.0013	.0010	.0021*	.0010	.0016
209	.0016	.0014	.0018	.0020	.0007	.0019
208	.0019	.0006	.0024	.0020	.0008	.0019
207	.0018	.0010	.0027	.0020	.0008	.0019
206	.0019	.0011	.0028	.0022*	.0008	.0022
205	.0019	.0011	.0028	.0022*	.0008	.0022
204	.0019	.0011	.0031	.0021*	.0008	.0028
203	.0019	.0009	.0034	.0021*	.0008	.0025
202	.0018	.0009	.0029	.0013	.0008	.0022
201	.0017	.0010	.0032	.0020	.0008	.0029
200	.0017	.0010	.0033	.0014	.0008	.0027
199	.0017	.0008	.0038	.0018	.0008	.0027
198	.0017	.0009	.0039	.0018	.0008	.0023
195	.0017	.0009	.0039	.0017	.0008	.0018
190	.0017	.0010	.0039	.0017	.0009	.0015
185	.0017	.0012	.0037	.0017	.0009	.0011
180	.0017	.0011	.0033	.0016	.0009	.0003
175	.0020	.0010	.0020	.0015	.0008	.0006
170	.0020	.0009	.0013	.0015	.0009	.0014
165	.0018	.0010	.0006	.0017	.0008	.0042*
160	.0017	.0010	.0011	.0017	.0007	.0040
155	.0016	.0010	.0020	.0017	.0008	.0027
150	.0017	.0010	.0012	.0015	.0007	.0022
145	.0016	.0009	.0001	.0015	.0008	.0029
140	.0014	.0010	.0003	.0013	.0008	.0028
135	.0013	.0009	.0001	.0012	.0008	.0027
130	.0011	.0010	.0011	.0011	.0008	.0022
125	.0011	.0009	.0017	.0012	.0008	.0018
120	.0010	.0009	.0018	.0012	.0008	.0018
115	.0010	.0009	.0018	.0012	.0008	.0021
110	.0011	.0009	.0016	.0010	.0008	.0025
105	.0012	.0010	.0011	.0011	.0008	.0028
100	.0012	.0008	.0005	.0011	.0008	.0029
95	.0013	.0009	.0000	.0012	.0008	.0026
90	.0013	.0009	.0003	.0013	.0008	.0021
85	.0013	.0009	.0006	.0013	.0008	.0015
80	.0013	.0010	.0004	.0012	.0007	.0011
75	.0013	.0010	.0001	.0011	.0008	.0005
70	.0012	.0010	.0006	.0011	.0009	.0001
65	.0012	.0010	.0013	.0012	.0009	.0003
60	.0013	.0009	.0016	.0013	.0009	.0005
55	.0012	.0009	.0018	.0011	.0009	.0011
50	.0013	.0009	.0018	.0011	.0008	.0013
45	.0012	.0008	.0018	.0014	.0009	.0015
40	.0013	.0008	.0016	.0013	.0008	.0020
35	.0011	.0008	.0015	.0011	.0009	.0022
30	.0000	.0008	.0011	.0004	.0008	.0025
26	.0000	XXXX	.0010	.0001*	XXXX	.0027

Figure 4

connect system), loading a new program into the calculator, and inserting a laser generator into the barrel chamber. Complete control is given to the system, then the calculator commands the head to pass through the cannon tube, stopping at 12-inch intervals to permit "settling of vibration". At each of these stops, X and Y axis readings are recorded and printed out.

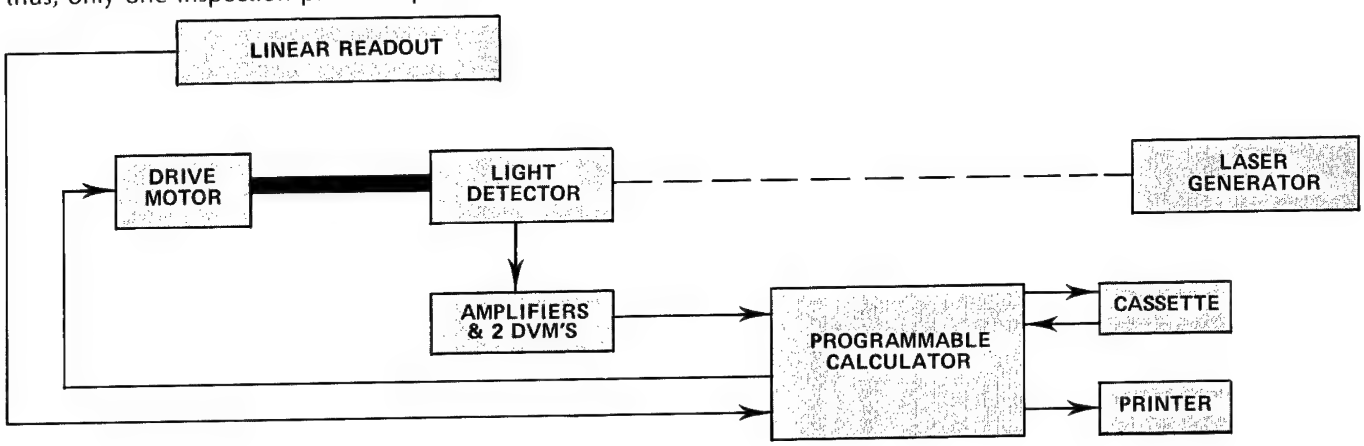
The measuring head does not rotate in this procedure, since X and Y axes must remain oriented during the "pass". Moreover, the laser beam used does not require zeroing at opposing barrel ends, since this is achieved by mathematically establishing a line of sight between the first and last measured points and mathematically "moving" remaining points toward that line of sight (see Figure 5). Finally, the barrel need not be rotated 90 degrees because the calculator mathematically compensates for droop; thus, only one inspection pass is required.

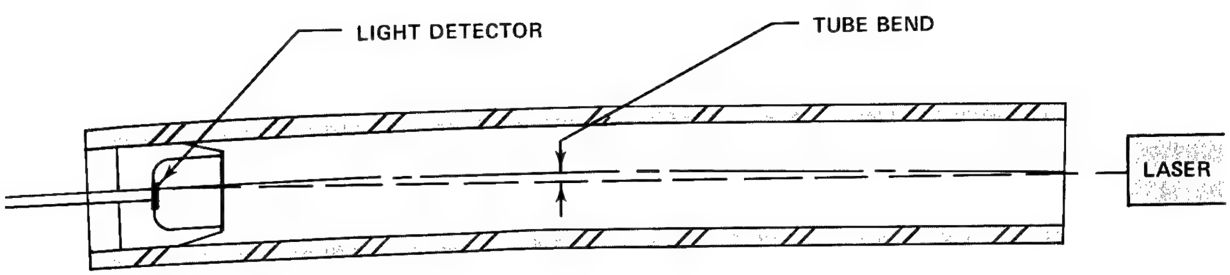
Laser Scan Replaces Eye

Inspection of cannon bore surfaces traditionally involved the time-consuming black light bore scope inspection method. The method required constant operator control (continuous observation through the scope) that often resulted in fatigue. Moreover, not all operators could easily spot flaws set off through black light excitation of the fluorescent particle treated bore surfaces. Consequently, in response to a 1976 MTT project request for a replacement system, a new laser scan setup was developed which incorporates a helium-cadmium laser unit that automatically locates and records all bore surface defects.

How It Works

Blue light from the laser excites the fluorescent particle treated bore surface and, if a flaw is spotted during a





MEASUREMENT OF TUBE BEND

Figure 5

scan, produces a yellow-green light (known as a "Magnaglo" indication). This light is detected by a photodiode, filtered optically to remove the blue light, converted into an electrical signal by the diode, and then amplified, processed, and displayed on a recorder.

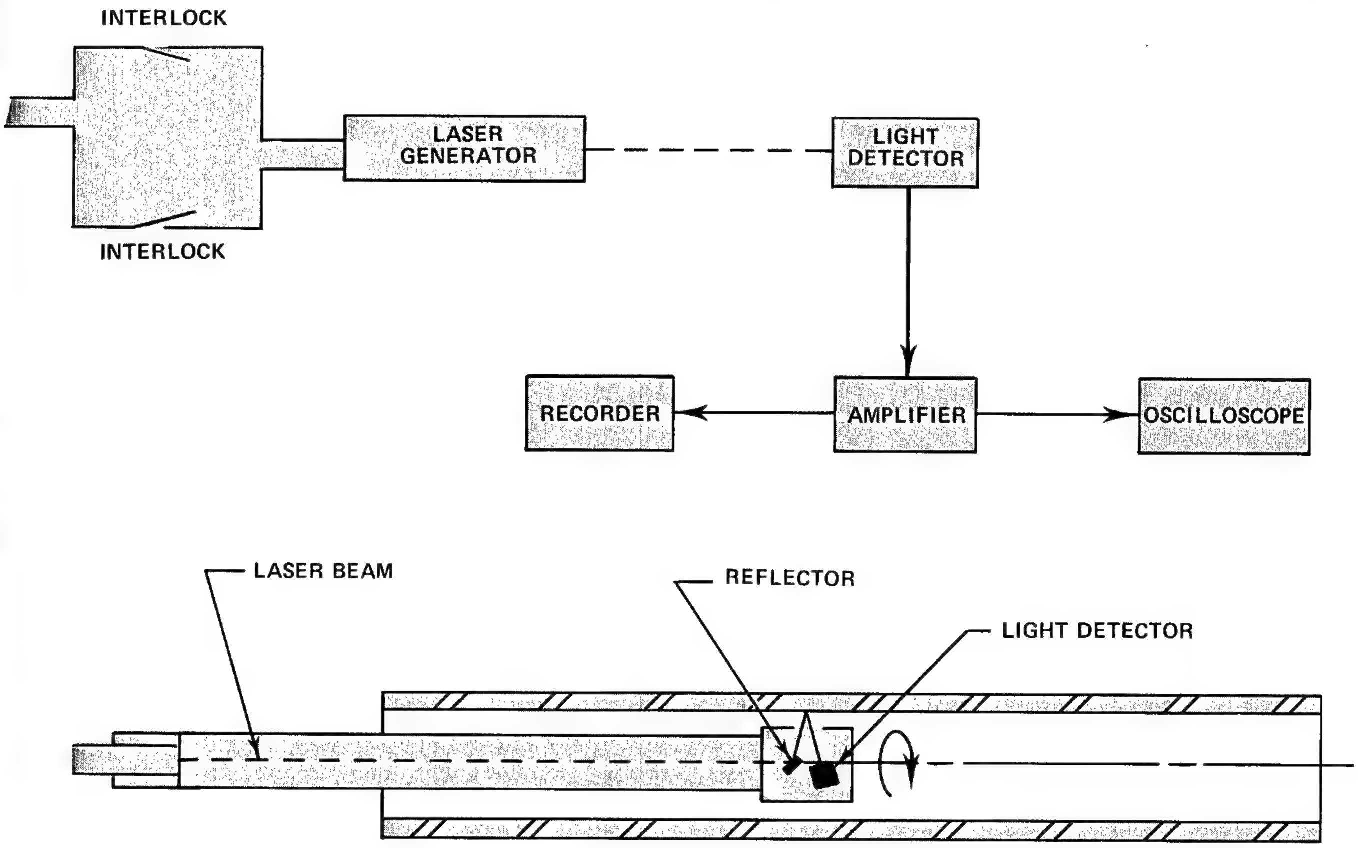
To operate the system, the laser beam is directed down a push tube in the barrel to the end of the bore, where a hollow shafted motor is located through which the beam passes. The motor rotates a photodiode and a mirror that reflects the beam 90 degrees to the barrel's inside diameter. The beam "traces" a circle in the I.D. and the resultant signal is carried from the diode to the system's electronics via slip rings (see Figure 6).

This technique, dubbed the "flying spot" scan, is quite similar to wirephoto transmission. The laser beam scans the cannon tube's I.D. in a spiral fashion at two revolutions per second, moving forward at 1/8 inch per second, producing a spiral scan with a 1/16-inch pitch. Synchronized to this rotation is a drum on a recording device. Immediately above the drum's surface is a spiral wrapped wire that extends the length of the drum and makes one complete revolution in that length. Recording paper is sandwiched between the wire and a knife edge running the width of the paper, and as the drum rotates, the intersection of the wire and knife edge moves in a straight line from left to right. A printout is obtained as electric current passes through and darkens the paper. To monitor the procedure, an oscilloscope displays a constant signal that is adjusted at a "threshold" level. Below this level is the background noise of the rifling. Detecting an indication (Magnaglo) causes a "spike" to appear above the threshold level and a buzzer to sound simultaneously.

Advantages Realized

Direct benefits of the cannon barrel inspection station and laser scan system are:

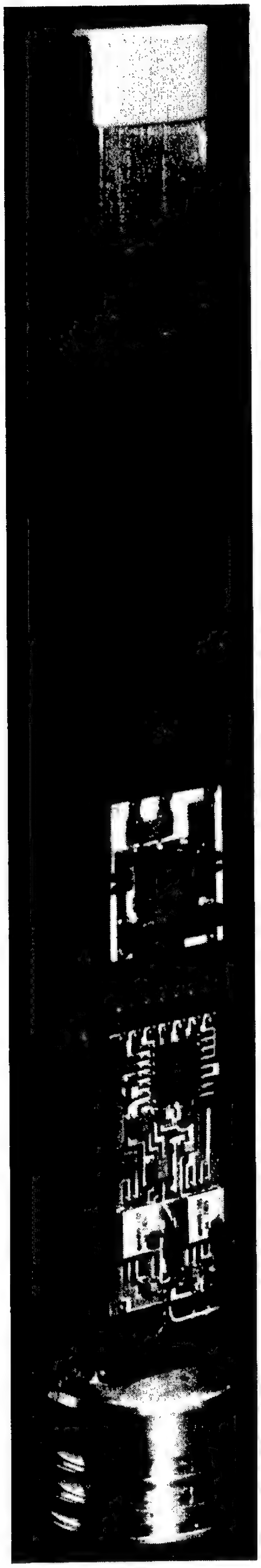
- Improved accuracy and repeatability in measurements and flaw detection through automation
- Elimination of human error and fatigue
- Time savings of 60 percent and 50 percent for barrel measurement and laser scan procedures, respectively.



LASER SCAN

Figure 6

Figure 1



WILLIAM SPAULDING is Engineering Section Leader in the Advanced Sensors Directorate of the Technology Laboratory at the Missiles Research and Development Command (MIRADCOM) in Huntsville, Alabama. His group is active in the development programs of several phased array antennas for air defense radar; he is an antenna consultant to the PATRIOT Project Office. He received a B.S. in Electrical Engineering from the University of Tennessee in 1958 and an M.S. from the University of Alabama at Huntsville in 1969. He holds two patents related to microwave phase shifters and is a U.S. representative in two international data exchange agreements pertaining to air defense radar technology.

Test For Key Radar Parts Developed

Microwave Characteristics Measured

As a result of work performed under a MIRADCOM MTT effort*, test fixtures and techniques have been developed to measure the microwave frequency characteristics of ceramic inserts prior to their assembly in a phase shifter for the PATRIOT missile system. The phase shifter is a key component in the PATRIOT's phased array radar. The new techniques should be applicable to other missile antenna systems or other microwave devices that use dielectric or ferride parts.

The new test techniques are precise enough to allow meaningful measurements at the part level of the two most important properties of the inserts—dielectric constant and its loss tangent. The precise measurement of dielectric constant enables inspectors to weed out defective parts that would lower the yield of the phase shifter if used in the assembly. Since such defects are not presently detected until the assembled phase shifter is tested, there are significant potential savings through eliminating needless assembly of defective parts.

Primary uses of the new techniques are expected to be

- Incoming inspection on the assembly floor

- Monitoring of the quality of sequential lots from a given vendor
- Comparison of parts from two or more sources.

The procedures will also provide effective trouble shooting of production problems and give insight into the cause of performance errors as they occur during the design process. When implemented, these techniques should improve part reliability and reduce both design and production costs.

Mission: Air Defense

PATRIOT is the U.S. Army's Air Defense System for the 1980's. It uses a phased array radar to guide interceptor missiles against enemy aircraft. Phased array radars are characterized by their antenna, which uses a large number of phase controlled radiating elements (about 6000 in the PATRIOT system) for electronic scanning of the radar beam. The microwave phase shifter controls the phased array activity. The PATRIOT phase shifter is shown in Figure 1. This part must be highly accurate, but inexpensive to make and reproducible on a unit to unit basis.

Utilizes Ceramics

The phase shifter used in PATRIOT and many other systems consists of a microwave transmission line partially filled with an yttrium-iron-garnet toroidal part which surrounds an alumina dielectric insert. A typical cross section of the device, which is about 5 inches long, is shown in Figure 2. A switching wire is threaded through the toroid to change its electromagnetic properties. This change affects the phase shift of the radar frequency energy propagating through the unit.

Both the garnet toroid and its insert are ceramic materials; their dielectric and ceramic properties must be controlled very accurately to realize the completed phase shifter performance error requirement of one part in 360 or about 0.3 percent. The primary source of potential error in the completed device is material and dimensional variation of these ceramic parts.

Improved Producibility Sought

A requirement to improve the producibility and yield in the manufacture of these phase shifter elements motivated the implementation of MIRADCOM's MTT program. Insertion phase reproducibility and insertion loss of production were considered particularly unsatisfactory and in need of improvement. At the start of the program, it was commonly believed that insertion phase errors were due largely to variation in the electrical parameters of the dielectric insert and the garnet toroid and that excessive insertion loss and resonances were due to inadequacies in the assembly of these parts. Accordingly, the principal objective of the program was to determine methods for measuring the microwave characteristics of phase shifter components before final assembly, thus avoiding use of unsatisfactory parts.

In order to measure ceramic properties at the part level, two microwave test fixtures were designed. These consist of lengths of waveguide (rectangular tubing for microwave transmission) with removable covers to allow easy access to their interior. One fixture was sized for the ceramic insert and the other for the toroid. The toroid fixture with a toroid in place is shown in Figure 3. Transitions (not shown) at each end of the fixtures were matched to microwave lines for test purposes.

Dielectric Insert Test Methods

Since the dielectric insert is not surrounded by the gar-

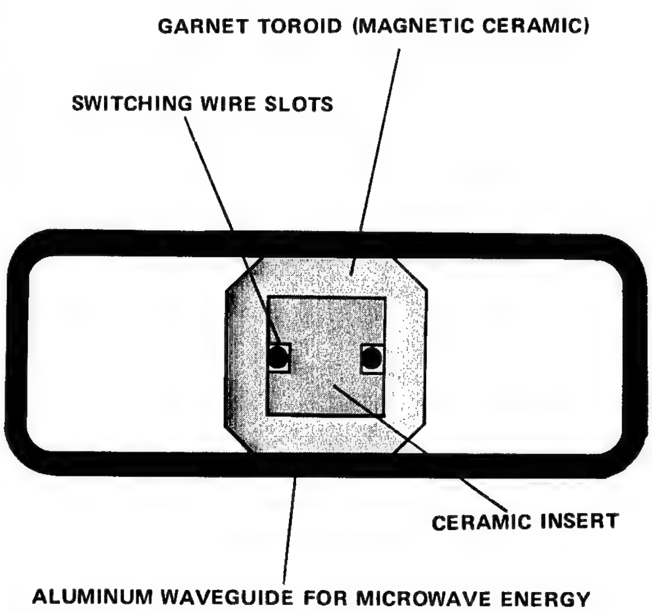


Figure 2

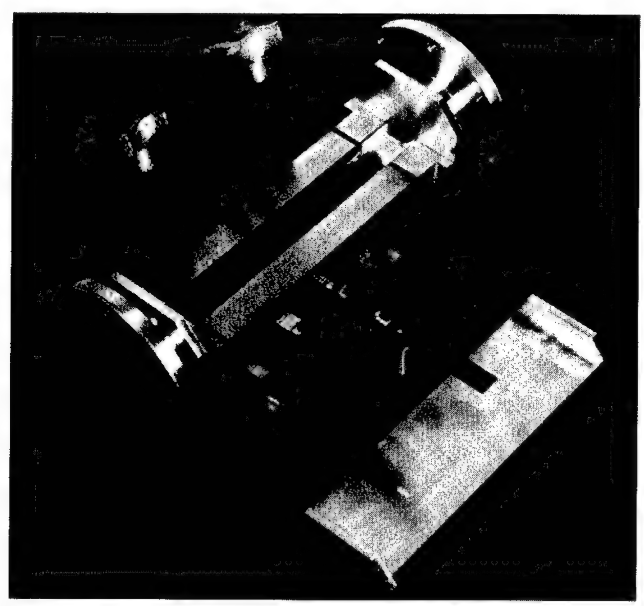


Figure 3

net toroid in the test fixture as it is in the final assembly, the test insertion phase cannot be directly related to the insertion phase of a completed phase shifter. Therefore, the most important parameters of the dielectric insert or rib become its dielectric constant and its loss tangent. Dielectric constant contributes significantly to insertion and differential phase, loss tangent is important to insertion loss. Thus, the insert measurement effort was directed toward determining these two properties. The fixture with the insert in place constitutes a two port resonant cavity capable of supporting several excitation modes in the S-band region. The cross section of the cavity is shown in Figure 4.

It is possible to calculate the resonant frequencies of such a cavity. Mode spacing is such that mode identification is not a problem. Coupling at the ends of the cavity is accomplished by leaving a short section of unloaded waveguide at each end of the loaded section. Selecting the right length for this unloaded section provides proper coupling.

The test may be used for absolute measurements of dielectric constant or for comparison of a dielectric insert with a known standard part. Before testing, the insert must be copper plated on both its top and bottom surfaces. This eliminates air gap errors. The plating requirement was uncovered during refinement of measurement techniques. Plating led not only to improved testing accuracy but also to a better understanding of the errors in the phase shifter design. As a result, the phase shifter was redesigned to include plating of the top and bottom walls of the garnet toroid to reduce the air gaps at the waveguide interface. For purposes of testing the dielectric insert, plating is applied only to the parts to be tested, and is removed before the insert is used in assembly. The 50 to 100 microinch copper plating is applied by sputtering, electroless plating, or other standard processes. After plating, the test piece is loaded into the cavity and placed near the center of the waveguide area. (Exact centering is not necessary.) The cavity is excited by a swept frequency source of 2.0 to 4.0 GHz, and the resonant frequency spectrum is observed. Deviation in resonant frequencies from the standard mode spectrum can be related to dielectric constant variation by using a computer model of the resonant cavity. Thus, the absolute dielectric constant of the insert material can be determined.

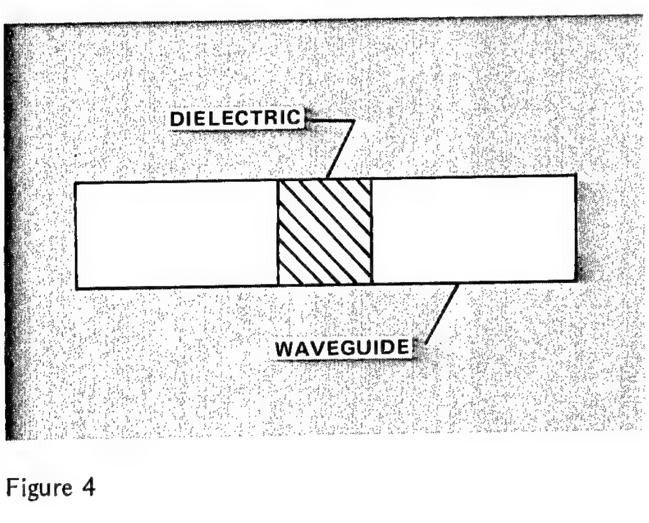


Figure 4

Toroid and Core Assembly Testing

The same fixture is used to test the garnet toroid and core assembly, since their outer dimensions are the same. The core assembly consists of the garnet toroid with the alumina piece inserted and bonded into the toroid center hole. It also has a switching wire passing through the entire length of the toroid via a slot in the insert. The fixture supports the test piece in the same manner as an element waveguide—i.e., between two flexible aluminum walls.

The toroid core assembly fixture allows direct measurement of insertion loss and phase of toroids or core assemblies. The measurements are made by placing the fixture in the test channel of a microwave network analyzer. The reference channel is completed through an appropriate length of coaxial cable. Insertion loss and insertion phase zero (reference) values are maintained by inserting a length of waveguide instead of the test fixture. In this manner, the references are maintained independently of any phase shifting element.

For testing toroids before assembly, plated parts are magnetically saturated before insertion into the test fixture by passing a 3 amp current through a two turn drive coil threading the toroid. This procedure is used to avoid errors that would result if switching wires were present in the fixture when an unloaded toroid is being measured. (The RF energy is coupled very strongly to the switching wires when no dielectric insert is used.) In this manner, insertion loss and insertion and differential phase are measured for empty toroids.

The differential phase measured is less than that of a loaded toroid, but it is related to the magnetic properties of the toroid and may be compared with a standard value to determine toroid acceptability. The insertion phase of an empty toroid correlates significantly with the insertion phase of the core assembly made from that toroid.

In order to test the core assembly after its toroid and insert have been tested and bonded together, it is placed in the fixture with the switching wires passing through the RF absorbers provided in the wire exit holes. The wires are connected to a driver that supplies the current pulse necessary to alter the magnetic state of the toroid. Switching the toroid to several representative states enables an operator to compare the insertion phase of the core assembly with a standard. The technique is evaluated by plotting phase values measured in the test fixture against phase values measured after loading the core assemblies into waveguides.

Satisfactory Precision Obtained

These techniques are capable of measuring dielectric ribs with a dielectric constant of approximately 50 to within an expected error of approximately 0.23 units. When comparing two parts, a dielectric constant difference of 0.135 units can be detected. This precision is sufficient to allow meaningful measurements to be made at the part level for ceramic parts of simple geometry.

The techniques and fixtures for measuring the toroid and the core assembly were found to be adequate to compare these parts with a standard and to identify acceptable population error bounds for assessing quality of the part.

Insertion phase measurements of the core assembly in the test fixture correlated well with measurements of the same cores when assembled into completed waveguide phase shifters. Representative data showing this correlation is plotted in Figure 5. The significance of this correlation is that the processes used in fabricating and bonding these dissimilar materials to form the critical core assembly of the phase shifter can be monitored to weed out defective parts at a very early production stage.

*The work was performed at Raytheon Company, Bedford, Massachusetts under Contract DAAK40-76-C-095 with Mr. Jim Birch as Project Engineer.

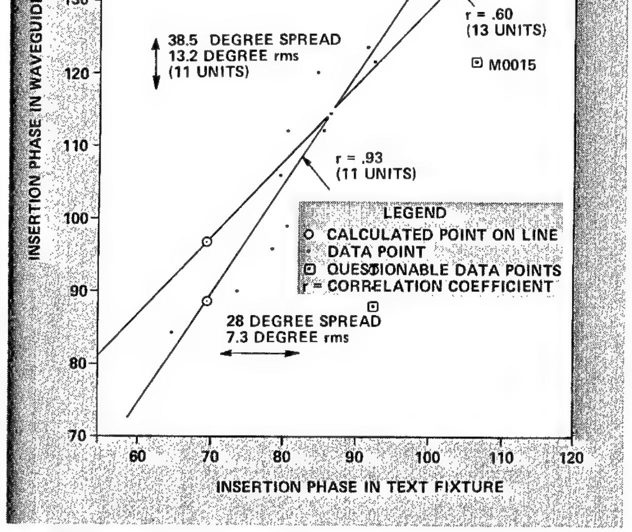
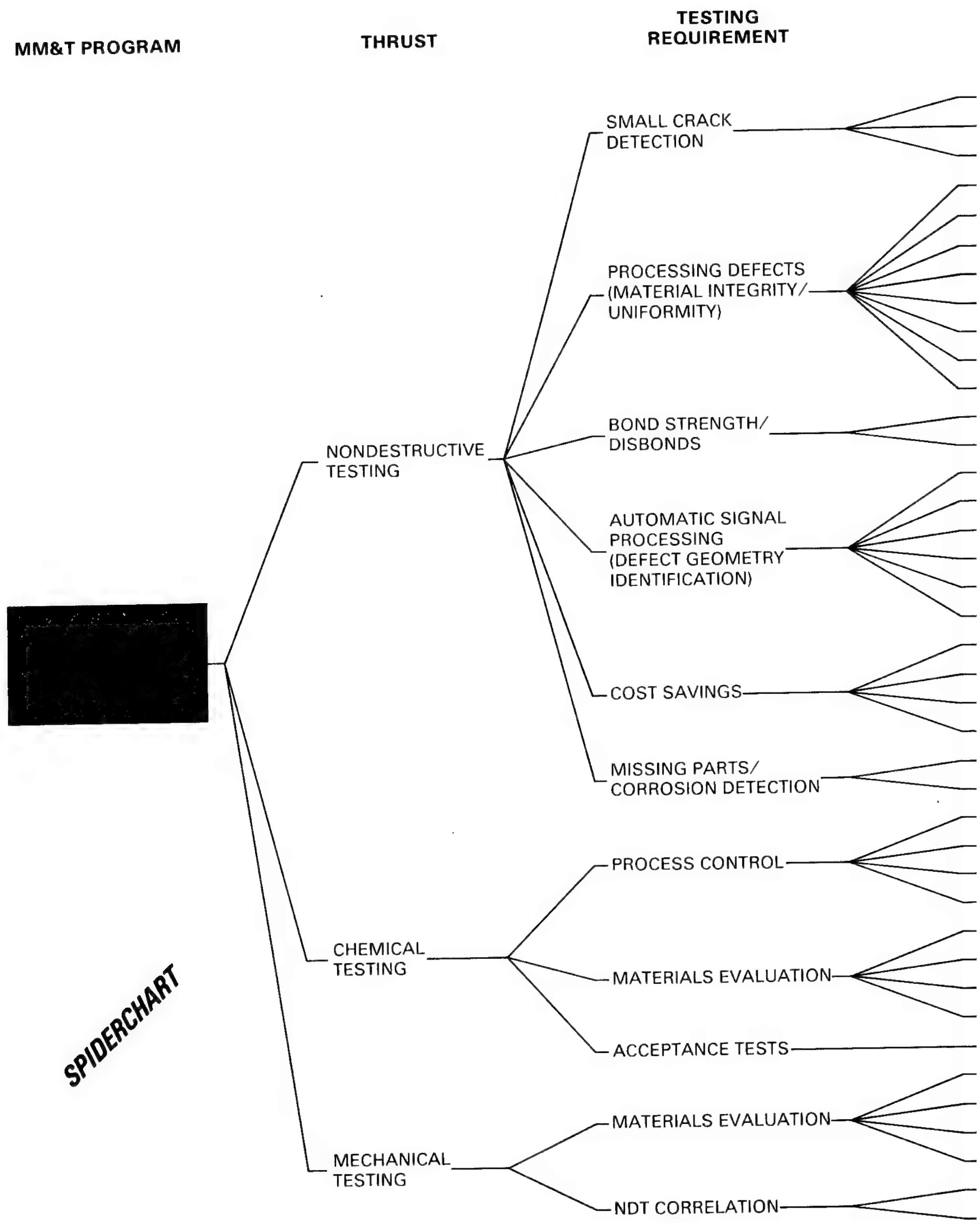


Figure 5

U.S. ARMY MATERIALS TESTING TECHNOLOGY PROGRAM SCOPE



SYSTEMS/COMPONENTS

MATERIAL/ TECHNIQUE	Turbine Engines	Ceramic Armor	Missile Radomes/Components	Projectiles	Engine Parts	Munitions	Gun Tubes	Aircraft Parts	Artillery Parts	Armor	Logistic Support	Motor Cases	Tank Components	Fuzes/Electronics	Fire Control System
CS	•	•	•												
AGMENTATION STEELS				•											
RENGTH STEELS					•	•	•					•			
CS	•	•	•												
D MATERIALS					•										
VES						•									
LASERS		•													•
ELS				•	•		•					•	•		
VOIDS														•	
SITES			•					•	•		•				
JOINTS														•	
DNIC SPECTROSCOPY			•								•	•			
DNICS/SONICS			•								•	•			
DNICS				•			•				•		•		
TING RADIATION				•		•							•	•	
IC PARTICLE				•									•		
				•			•		•				•		
APHY						•									
C EMISSION			•										•		
TIC DECISIONS	•	•	•	•	•	•	•	•	•		•		•		
RAPHY—FILM COSTS				•		•							•		
NEOUS EXAMINATIONS						•									
RE EXAMINATIONS				•		•			•						
						•								•	
N RADIOGRAPHY				•				•	•		•				
ANT MIXES			•			•									
S	•	•	•												
ITES			•					•		•			•		
MERS								•		•	•		•		
S	•	•	•												
ITES			•					•		•			•		
MERS								•		•	•		•		
	•							•		•			•		
MASKS											•				
S	•	•	•												
ITES								•		•			•		
MERS								•		•	•		•		
	•							•		•			•	•	
E TOUGHNESS	•	•	•	•						•					
ICAL PROPERTIES	•	•	•	•						•					

From Beer Cans and Gum Drops to Bullets

21st Century Production Techniques Today

Using concepts and techniques borrowed from the manufacture of items as diverse as beer cans, drugs, and gum drops, the Army has completed installation of an ultramodern production facility for small caliber cartridges at its Lake City plant near Independence, Missouri. The new facility promises as much as a tenfold increase in produciton rate over conventional operations. Significant cost savings also will be realized from more than a 60% reduction in manpower and more than a 50% reduction in scrap. At full production, this fully automated plant turns out 118 million 5.56 mm cartridges of the very highest quality per month; the Army is considering similar facilities in the future for 7.62 mm and 30 caliber cartridge production.

Computers Call the Shots

With minicomputers directing the operations, the Army terms Lake City the most automated, efficient, and responsive small caliber ammunition manufacturing system in the world. The automated production system of the new plant already is proven. An earlier prototype system installed at the Twin Cities Plant in New Brighton, Minnesota turned out 40 million cartridges before it was laid away in June, 1975. The prototype operation proved the success of the concept and the ability to achieve anticipated production rates; meanwhile, many improvements were made in the system.

Total cost of the production system was about $102 million, including nearly $92 million in facilities (see Table

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1). At full production, conventional processing requires 927 direct and 213 indirect operators. The SCAMP system requires only 328 direct and 142 indirect. For peacetime production of 40 million/month, the direct labor force is reduced from 309 to 113 and indirect labor remains constant at 89. Scrap rates have been reduced from 4 or 5 percent with conventional processing to 2 or 3 percent for SCAMP.

Item	Contractor	Cost, $1,000
Case Submodule	Gulf & Western	23,700
Bullet Submodule	Gulf & Western	15,000
Primer Insert Submodule	FMC Corporation	6,900
Load and Assemble Submodule	Gulf & Western/Perry Industries and Hoppman Corp.	13,000
Automatic Material Handling System	Rohr Industrial Systems	2,300
Packaging	Gulf & Western	5,100
Building Renovation	Sharpe Brothers Construction	10,000
Process Quality Control System	Science Applications, Inc./Honeywell and Battelle	810
Ballistic Test Submodule	Systems Consultants	700
System Integration et al	Remington Arms Corporation	14,290
	Total	91,800

Table 1

Rapid Fire Weapons Force Change

The start of production at Lake City culminates an effort that began in 1968 at Frankford Arsenal. At that time, new weapons with much higher rates of fire had been developed for the Vietnam conflict and a need had arisen for faster, more efficient cartridge processing. Small caliber ammunition was still being produced by World War I processes and World War II equipment. Therefore, the Army launched its Small Caliber Ammunition Modernization Program (SCAMP), which began looking for improved methods of manufacture. However, the Army recognized that cartridge processing was, if nothing else, highly reliable and that any change would have to be significant. It appears that the Lake City facility will make the long wait and careful planning worthwhile.

Turn Of The Century Technology Today

One of the most remarkable facets of the program has been implementation of the highly successful management procedures followed since the program's inception. The Project Manager instituted intensive management techniques (*ManTech Journal* , Fall 1976, "Integral Plans Review All Possibilities") to make sure this highly complex program kept within financial and schedule milestones and that all technical objectives were attained. Controls included complementary Configuration Management Boards at Lake City and at the Project Manager's Office in Picatinny Arsenal, New Jersey. Continual monitoring and regular technical, financial, and scheduling reviews between the Project Manager's Office and the contractor operator of the plant in Lake City ensured achievement of these objectives. The program represents a classic example of military and private industry coordination, one which has produced a spectacular breakthrough—production techniques of the Year 2000 put into operation today.

The new installation will replace present processing that utilizes old crank presses turning out approximately 100 parts per minute. This outdated operation is highly labor intensive and presents both safety and pollution hazards. It is basically the same process used since the early 1900's, requiring large numbers of machines and operators producing at relatively low rates. Most of the equipment was procured during WWII for 30 caliber ammunition.

The SCAMP system offers production rates of 1200 parts per minute per line, improved quality, greater availability of equipment, marked reductions in manpower, reduced scrap losses, less startup time, better space utilization, and improved safety and pollution standards. The original goal of reducing costs $10 per thousand cartridges appears to be achievable. This represents a cost savings of approximately 16 percent. To accomplish all this, the SCAMP effort emphasized mechanization of hand operations, conversion of batch processes to continuous processes, and computerization of material handling, process tooling, and inspection systems.

Cartridge Manufacture, A Complex Operation

The production of small caliber cartridges is a complex process that requires

- Forming the cartridge case from a brass cup
- Inserting primers into the case
- Fabricating the bullet
- Loading the propellant and assembling the bullet and the cartridge case
- Acceptance proof testing
- Packing.

The first four steps require many press operations and several in-process inspections to ensure quality. Current processing uses many different presses for each operation, with manual transfer of parts between processes. The SCAMP system overcomes this inefficiency by using submodules for each of these steps with fully automated feeding and transfer of parts between submodules. The first four submodules utilize a complex of rotary turret presses each with 24 stations operating at 50 strokes per minute. This provides production rates of 1200 parts per minute. Since the Lake City plant will include five full production lines, its ultimate capacity will be 6000 cartridges per minute. The automated packing submodules are designed to maintain this rate. This system also provides 100 percent online inspection at key points during fabrication in addition to offline inspection gages and the final

submodule, which provides ballistic tests for selected samples. The total operation is monitored by a production quality control system; Figure 1 is a block diagram showing the SCAMP submodules and flow of work.

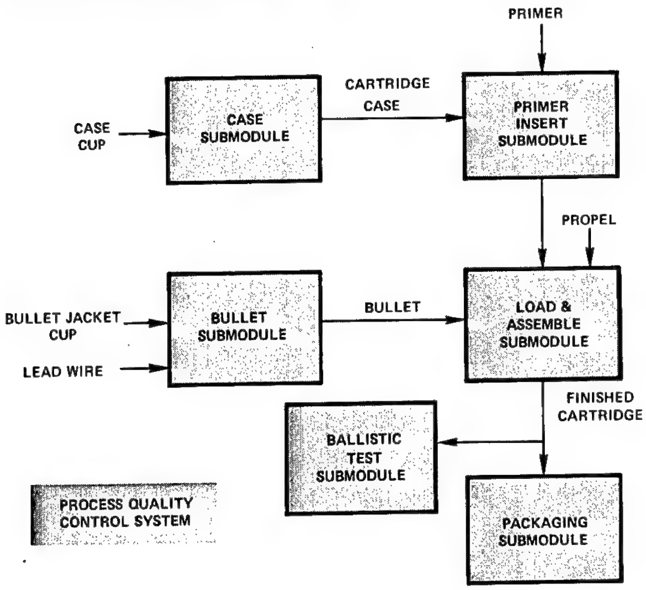

Figure 1

Rotary Turrets, Modular Tooling the Keys

A key to the success of the system is the use of high speed rotary turrets in series in order to get volume production. The Army borrowed this concept from the beer can industry, where it has proven highly efficient. While the presses operate at only 50 strokes per minute, just half the rate of some of the present crank presses, they are turning out 24 parts with each revolution. Another key is the use of modular tooling to reduce downtime. Tools are preset on an offline tool simulator and then snapped into the turrets with minimum downtime. Also of utmost importance is the **automated inprocess inspection system,** which provides early ejection of defective parts.

The **cartridge case submodule** illustrated in Figure 2 was developed by the Gulf and Western Advanced Development Center. Starting with a brass cup, nine rotary presses in a series of 14 turrets, each with 24 stations, form and pierce the cartridge case. The operation includes intermittent induction anneals and washes. The two draw process shown replaces a standard three draw process, and the induction anneal is used instead of gas fired annealing furnaces. Transfer between turrets is accomplished by a chain handling system.

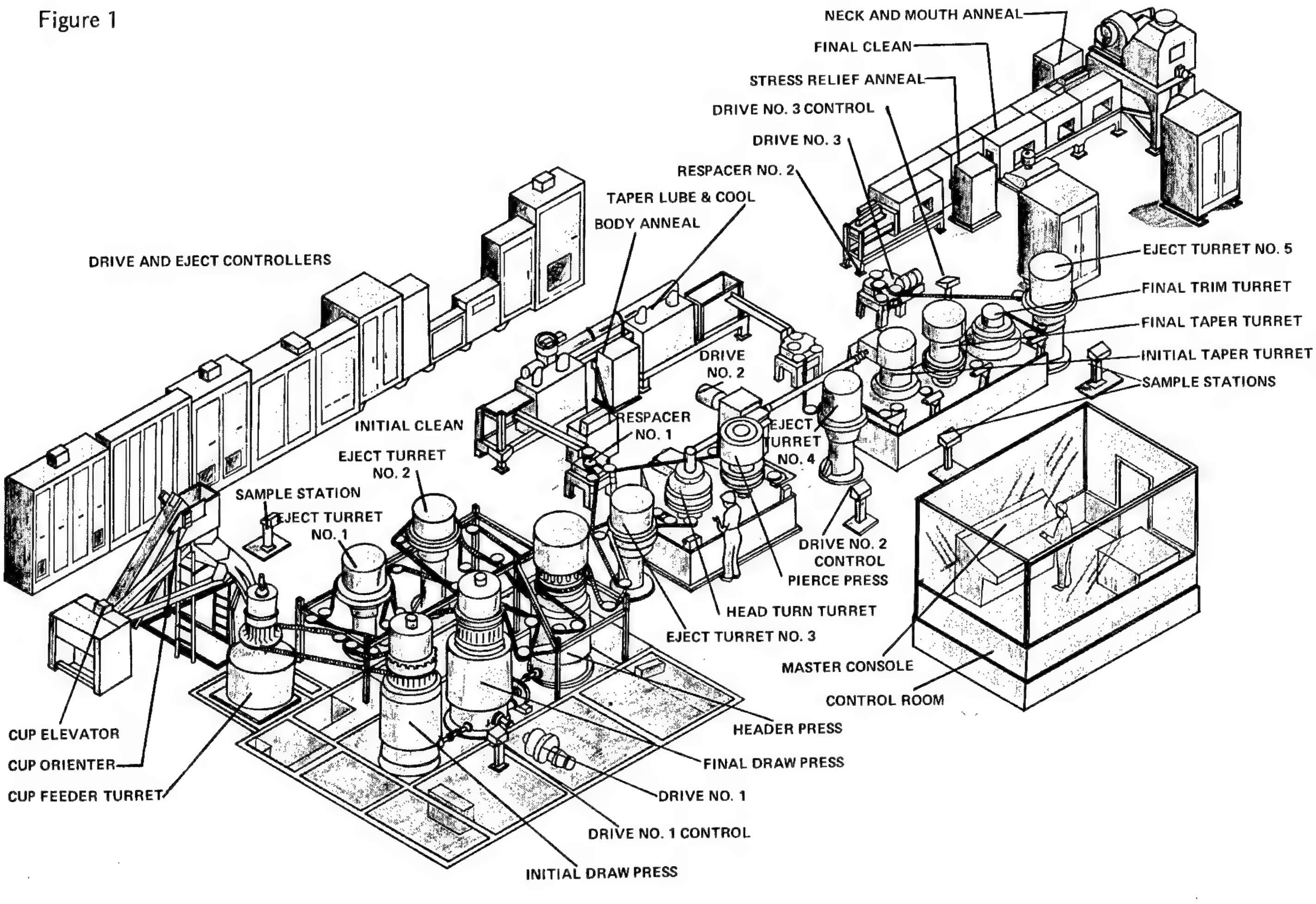

Figure 2

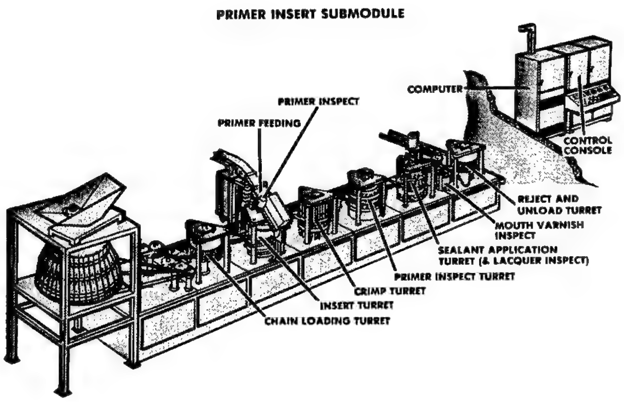

Figure 3

The **primer insert submodule** inserts explosive primers into the cartridge cases, applies sealant, and automatically inspects every cartridge. Figure 3 illustrates this system which was developed by FMC Corporation. Its six turrets also have a chain transfer system, each with 24 stations, and remote control by minicomputer precludes operator hazard.

Gulf and Western also developed the **bullet submodule** shown in Figure 4, which has eleven 24 station turrets that convert brass cups and lead slugs into precision quality bullets. Rotary transfer between the working turrets moves the parts through the system as opposed to the chain transfer used on the previously described submodules. Like the case submodule, this system is computer controlled and utilizes preset modular tooling.

The prototype **load and assembly submodule** developed by Perry Industries feeds bullets and primed cases, precisely measures the propellant and loads it into the primed cases, then assembles the bullet and crimps the cartridge. The most critical portion of this operation is the propellant fill, which must be extremely precise. To ensure that precision, Perry adapted a turret similar to that used by the drug industry. In process inspection covers cartridge profile, alignment, and propellant level, the latter accomplished by an isotopic gage. Again, the process is remotely controlled by minicomputers to eliminate hazards to the operator. The follow-on five systems (Figure 5) were built by Gulf and Western's Advanced Development Center utilizing the same powder dispensing turret.

Frankford Arsenal developed the **packing system** which, consists of seven standard packing machines adapted to a rate of 1200 parts per minute. It can pack ten round clips into bandoliers and boxes and can also pack 20 round cartons, then automatically palletizes wooden crates for shipment. The production system was built by Gulf and Western and is already in operation as part of the conventional production line at Lake City.

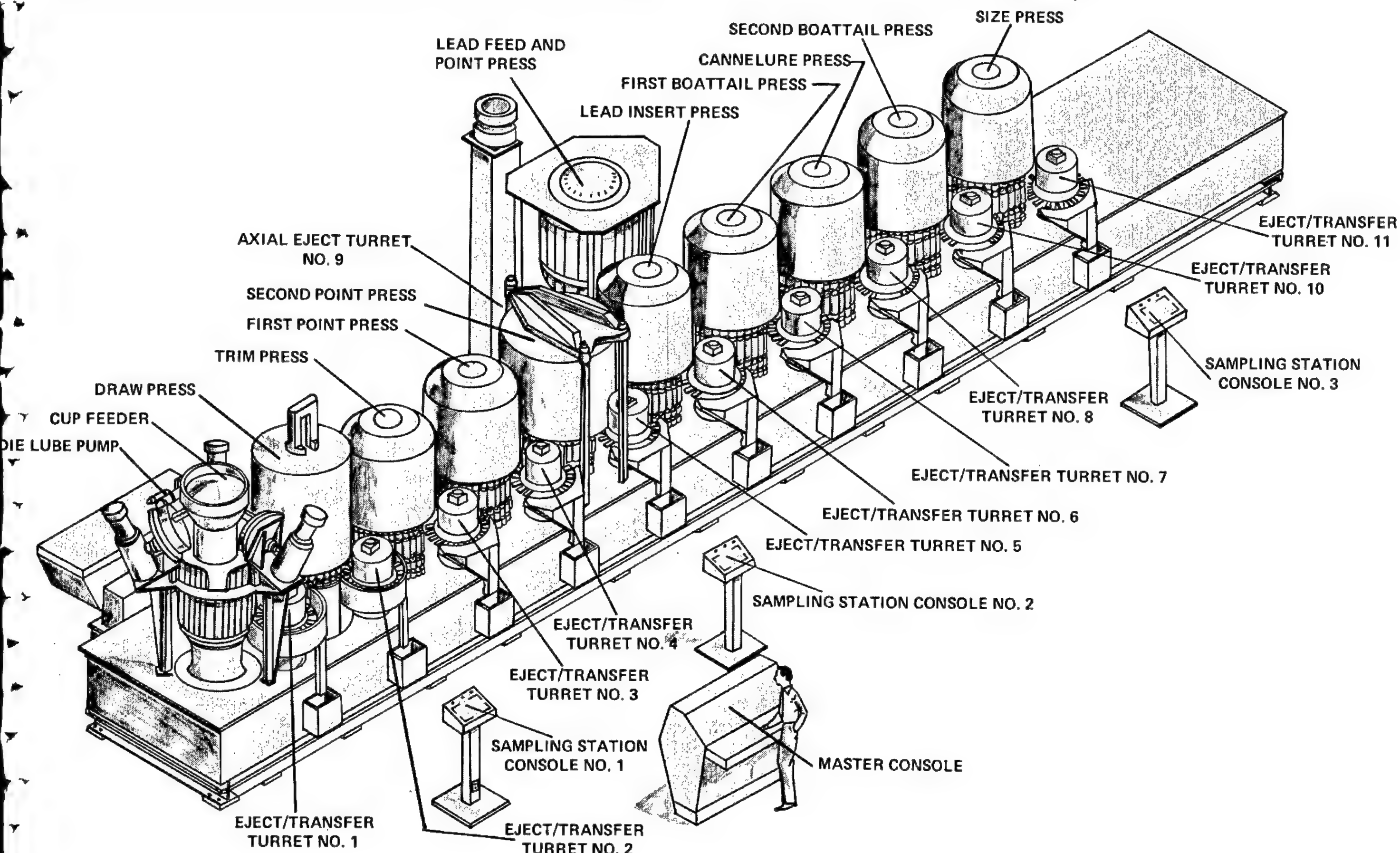

Figure 4

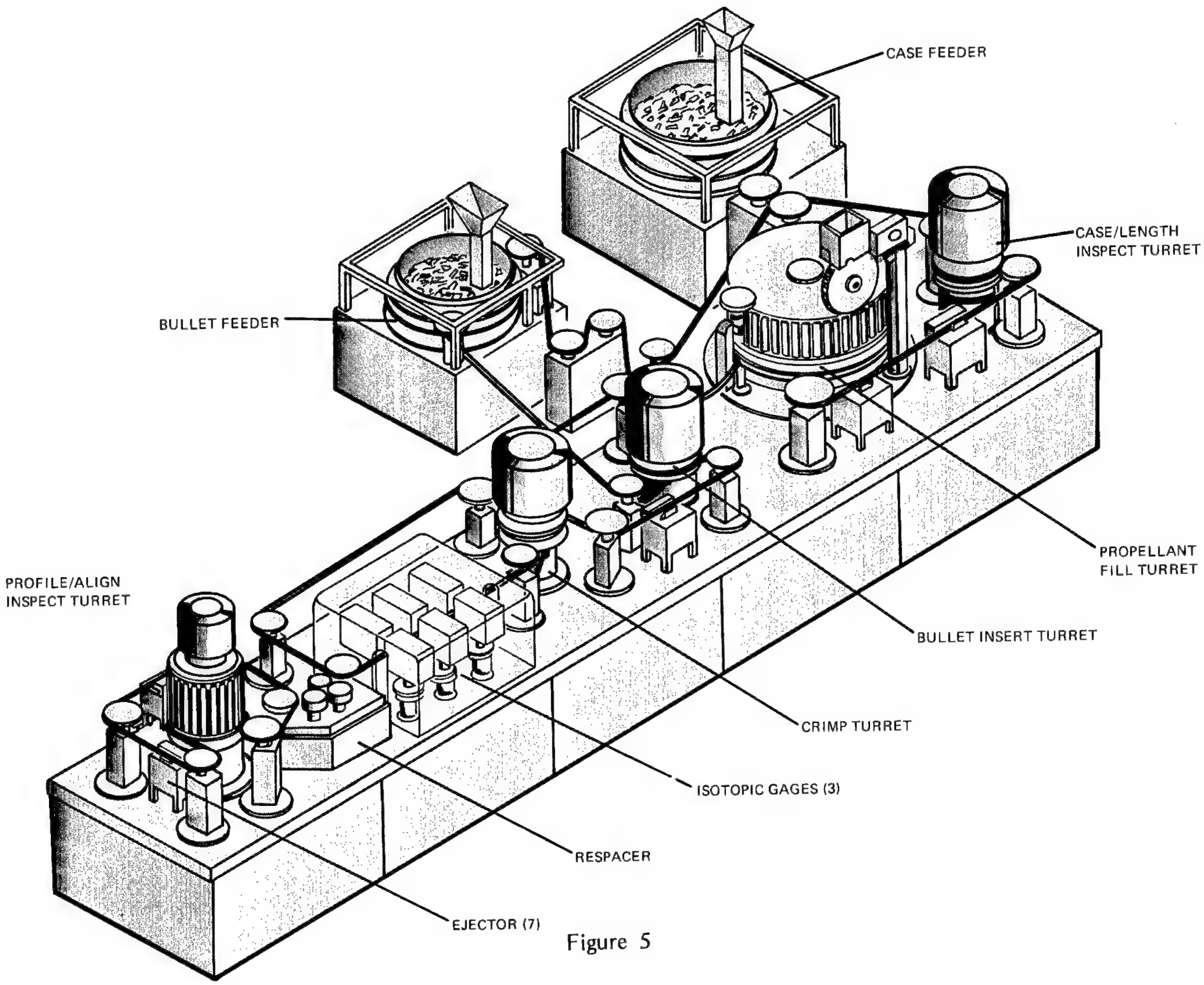

Figure 5

Quality Closely Monitored

The **ballistics test submodule** (Figure 6) fires a sample of the ammunition produced to acquire simultaneous data on accuracy, velocity, chamber pressure, and other critical characteristics. This system, applicable to both acceptance and process control, was developed by Systems Consultants, Incorporated.

Online inspection systems are provided for both the cartridge case and the complete round. These are tied directly to the cartridge case and load and assemble submodules, respectively, and they automatically eject unacceptable parts. The cartridge case inspection system provides a 100 percent check on (1) vent hole presence; (2) profile characteristics including length, head thickness, gas seal length, head diameter, and extractor groove diameter; and (3) both surface and subsurface flaws. The finished cartridge inspection system inspects for surface flaws over five cartridge zones. These automated inspection systems, developed by Battelle Northwest, utilize scattered light electrooptical instrumentation, a totally new concept in high speed inspection of components. They are described in detail in a related article in this issue of the ManTech journal and are the first quality control systems that inspect components "on the fly". **Offline gage measurements** for both bullets and cases are also provided. The gages check a large number of characteristics automatically during a five minute period. Data from the test is fed into a computer, printed out, and then fed into the **Central Process Quality Control System.** That system, which has been designed and built by Science Applications, Incorporated, provides data on each of the submodules both individually and collectively. It also provides management information, continuing quality control data, and sensor data to monitor tool wear.

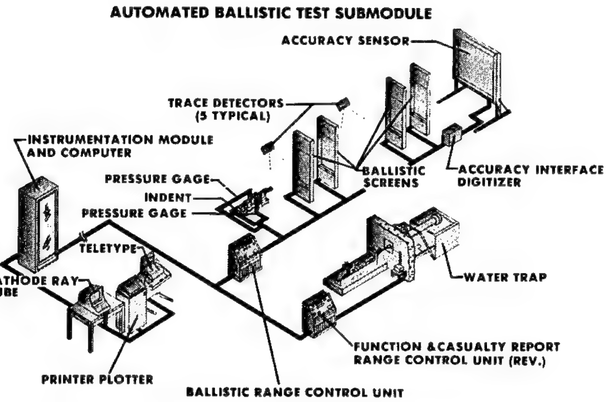

Figure 6

Ten Hours' Storage Provided

The production layout also includes an **automatic material handling system** built by Rohr Industrial Systems, Incorporated. Basically, it consists of individual systems for each of the first five submodules. The modules have independent operation and control in both manual and automatic modes. Multihopper storage provides up to ten hours of storage between submodules for each of the five lines—for example, fifty hours of production from the cartridge submodule can be stored ahead of the primer submodule.

Prototype Operation A Success

The prototype system operated at Twin Cities during 1974-1975 demonstrated its ability to economically produce quality 5.56 mm ammunition at one shift rates of 7 million rounds per month, meeting the project goal. The system turned out 40 million rounds exhibiting quality equal to or better than standard production. Accuracy of the ammunition exceeded that of conventionally produced cartridges and approached that of "competition match grade" ammunition. For this prototype operation, only limited material handling and process control systems were installed. The rest of the system was complete, however, including an entire ballistic test submodule.

During prototype production, baseline operating speed and submodule tool setting procedures were established. Manufacturing and quality assurance procedures were developed, as were operational maintenance and manning policies. Some 500 equipment changes were defined, incorporated into the production system, and demonstrated. Finally, a computerized data base was developed for further evaluation of the production system. Total cost of the prototype system and related engineering was about $36 million.

Gumdrop Technology Also Important

One of the major improvements in the production system has been with the feeders, which gave significant trouble during the prototype phase. Ten different feeders are used in the completed system, with each required to orient and feed parts up to 1200 per minute. New approaches are still being tried, but with improvements made to date, acceptance feed rates of 98 percent or better have been achieved.

Hoppman Corporation has developed most of the feeders by adapting feeders used in gumdrop production. They have made these centrifugal bowl feeders more rugged and improved their chutes. Work is now directed toward prefeed techniques that will provide a more uniform rate of feed. The goal is to achieve 100 percent fill and 100 percent reliability at 1200 parts per minute.

Lake City Rejuvenated

At Lake City, the Army has completely renovated a 350,000 square foot building at a cost of about $10 million to house the new production facility; Remington Arms Corporation operates the new plant. This facility includes five of each of the five major submodules, i.e., five complete production lines. (A single ballistic test submodule serves the entire system.) The prototype process quality control system (PQCS) was developed by Honeywell; the follow-on PQCS, which was built by SAI Corporation, ties the entire operation together, and the automatic material handling system allows operation of the submodules in any combination. The facility has a capacity of 118 million 5.56 mm cartridges per month on a three shift, 500 hour per month basis.

Figure 7 illustrates the production system layout. Each case submodule control is in its own noise proof, air conditioned room. The bullet submodule control is in a single noise proof, air conditioned room. Provision is made for a separate bullet manufacturing submodule as needed for tracer ammunition. Both the primer insert and load and assemble submodules are isolated for reasons of safety, with operators located in control rooms overlooking the operations. The locations of the process quality control system and preprocess computers are also shown.

One production line was proven out in December 1978, after which it was accepted and production began.

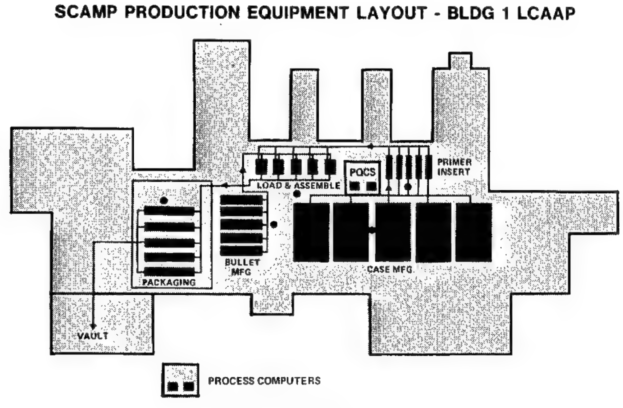

Figure 7

Automated System Superfast, Accurate

Cartridge Cases Inspected On Line

W. J. COLEMAN is manager of the Optics, Lasers, and Holography Section, Battelle Pacific Northwest Laboratories, Richland, Washington. Mr. Coleman received his B.S. Degree in Engineering Physics from Walla Walla College in 1960. Since joining Battelle in 1965, he has been responsible for programs in electrooptical design and system fabrication, including development of complex lens systems and laser alignment and measuring systems. At present, Mr. Coleman is directing research and development efforts in the areas of laser applications and the development of high speed electrooptical inspection systems.

K. L. SWINTH received his M.S. Degree in Radiological Sciences from the University of Washington. He has been employed at Battelle Northwest since 1965, where he has been involved in several projects in the areas of nuclear instrumentation, radiation dosimetry, medical physics, neutron radiography, and general instrumentation. His experience has been primarily in research concerned with the development and evaluation of instrumentation concepts. Mr. Swinth has authored over thirty publications and has submitted several invention disclosures in his areas of research. Currently, he is Assistant Project Manager for the Army program leading to the development of high speed cartridge case inspection and reject systems.

Introduction of high speed automated assembly of 5.56 mm cartridges at the Army's Lake City Ammunition Plant near Independence, Missouri demands inspection devices that can keep pace. (The small caliber ammunition manufacturing program, SCAMP, was detailed in the article immediately preceding this article.) Battelle's Pacific Northwest Laboratories has developed an automatic inspection and rejection system for small caliber cartridge cases that meets this need; the system is an integral part of the cartridge submodule in Lake City's automated line. The cartridge case measurement eject system (CCMES) inspects cases at the rate of 1200 per minute for each production line, ejecting those that do not meet specifications.

During inspection, several dimensions comprising the case profile are gaged to ±0.001 in.; the presence of a vent hole is verified; and the case is inspected for surface flaws. Electrooptical techniques are used for all flaw measurements, except certain ones that are determined by eddy current techniques. The CCMES inspection module, featuring a mechanical handling system coupled with computer control and data acquisition, is illustrated in Figure 1.

case image to allow projection of both edges for a measurement onto a single diode array.

The head to shoulder measurement uses a special fixture which chambers the gas seal area. This fixture exerts a light load during the measurement, thus simulating the present head to gas seal length measurement techniques. The diode array detection elements are on a 0.0005 inch center to center separation. This spacing allows one to one imaging while maintaining the required precision. Data averaging is done using a twenty scan average.

The vent hole monitor verifies the presence of a vent hole in the case by passing light through the case; the conceptual design is illustrated in Figure 5. A slightly converging source of light enters the case through the vent hole and exits at the mouth where it is detected. To prevent problems associated with light "leaking" past the side of the case, the electronics are designed to make sure that the light is present at the detector for a selected angular rotation of the transfer wheel. This is accomplished using an optical encoder. Because a vent hole signal results from the unobstructed light when no case is present, the presence of a case is thus verified.

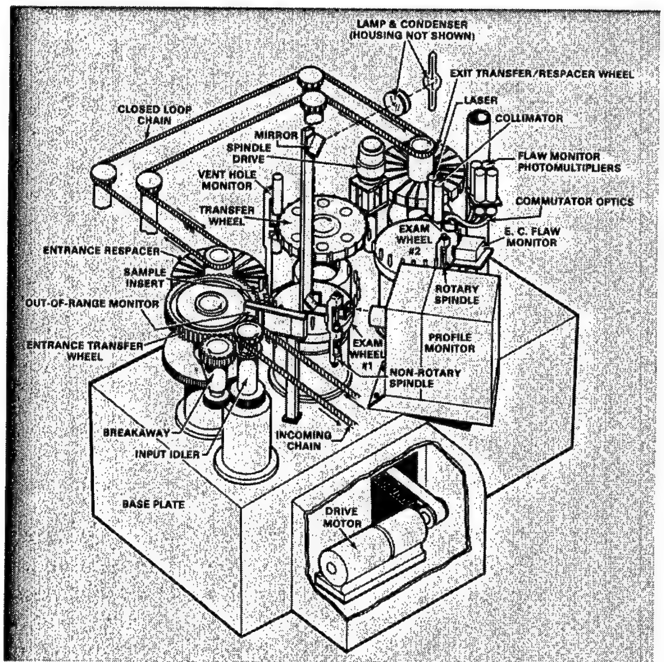

Figure 1

The initial system was installed at the Twin Cities Plant near Minneapolis/St. Paul, Minnesota for use with the SCAMP prototype. As with other parts of this prototype, the CCMES design has been upgraded in accord with prototype experience.

Diode Array Monitors Profile

The profile monitor measures head diameter, extractor groove diameter, head thickness, gas seal length, and total length as shown in Figure 2. This is done by an optical diode array gaging technique. Significant advances in linear diode array technology provide scans by multiple fixed diode arrays rather than optical scans of the case profile past a single diode array as was done in the prototype system. (For technical details of that system, see: Coleman, W.J., etal, "On-Line Automatic High-Speed Inspection of Cartridge Cases", Standardization News **3** (3), 31-34, March 1975). The conceptual design is shown in Figure 3.

Figure 4 shows the conceptual electronics layout for profile measurements. A common signal source, start trigger, and multiple scan control is used. Each array has a data buffer. This facilitates trouble shooting and computer data acquisition. The monitor uses fiber optics to "fold" the

PROFILE MEASUREMENT

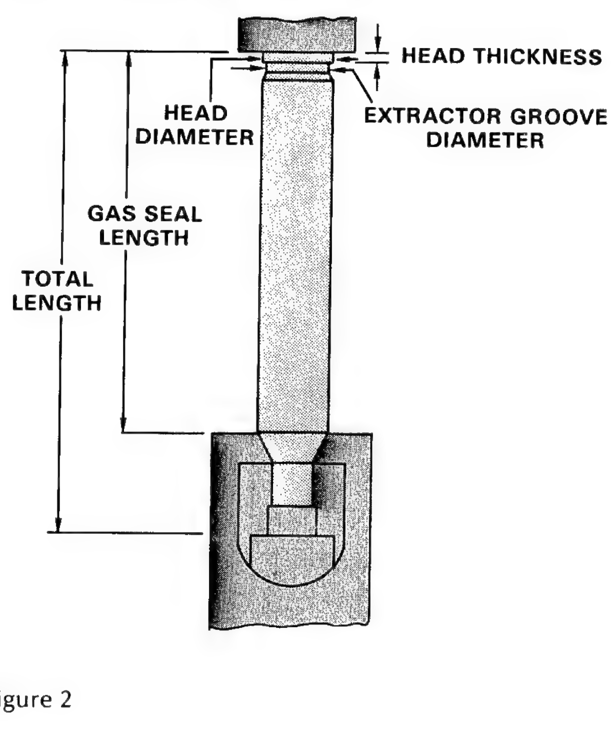

Figure 2

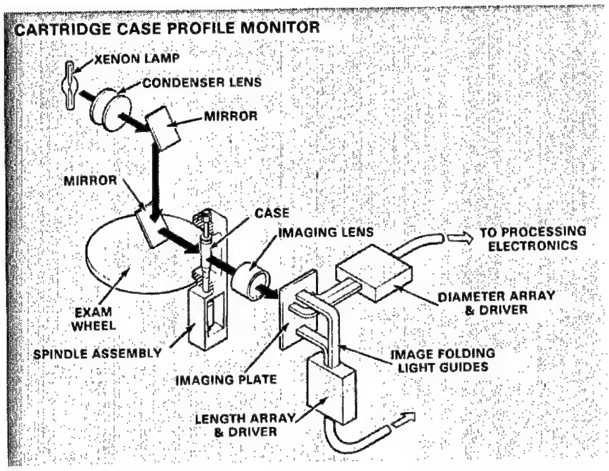

Figure 3

Laser Scattering Indicates Surface Flaws

The case surface flaw monitor utilizes optical scattering instrumentation to detect flaws. A conceptual layout of the surface flaw monitor hardware is shown in Figure 6. Each test position holds and rotates a single case by means of spindle tips inserted into the case mouth and primer pocket.

As the mechanical handling wheel rotates, a single laser source illuminates cases in sequence through lens/prism components. Each test position has line source production optics and a fiber optics receiver bundle. A flaw in the case will scatter light from the case into the receiver. This light is directed to a single set of optical detectors via a single detector fiber optic bundle. The receiver fiber optics are coupled to only one test station at a time.

The wheel motion with the collimated laser illumination and individual test position lens/prism assembly provides automatic spindle position switching. Scattered light from the case zones is separated by segregating specific portions of the receiver fiber optic aperture according to case zone. Light from each zone is directed to a separate detector and electronic signal processor channel. The flaw signal is processed using band pass filtering. Automatic gain control is used to compensate for variations in individual bundle transmission characteristics.

Flaws are indicated and detected when the signal exceeds a prescribed threshold level for a preset time. Three amplitudes and pulse widths are used per zone for reject determination. Reject signals are fed to the computer to indicate case quality for data inventory and to start or inhibit the computer controlled case reject cycle.

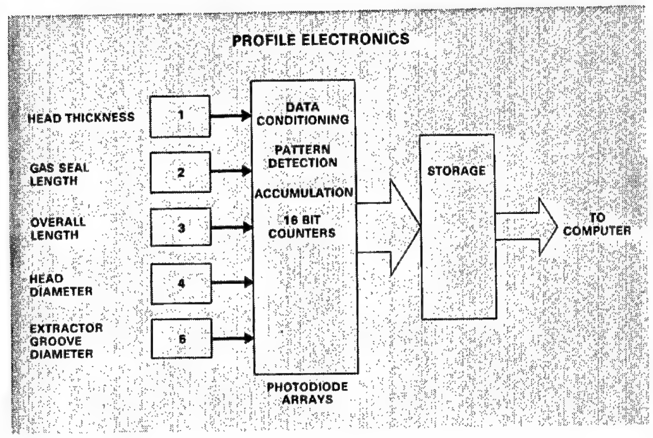

Figure 4

Eddy Current Flaw Monitor

On the first cartridge case measurement eject system, the eddy current device monitored thickness. Operation of this system at the Twin Cities Plant indicated that thickness was not a serious problem and did not warrant on-line measurement. It became apparent, however, that the eddy currents had the capability of detecting very tight folds and splits that were, at times, difficult to detect with the laser surface flaw monitor. In addition, it was noted that very tight mouth folds were readily detected with the eddy current monitor. In the new measurement system, the eddy current system is used solely as a flaw monitor. The station utilizes two eddy current coils, one located near the head area of the case where the body splits occur and one

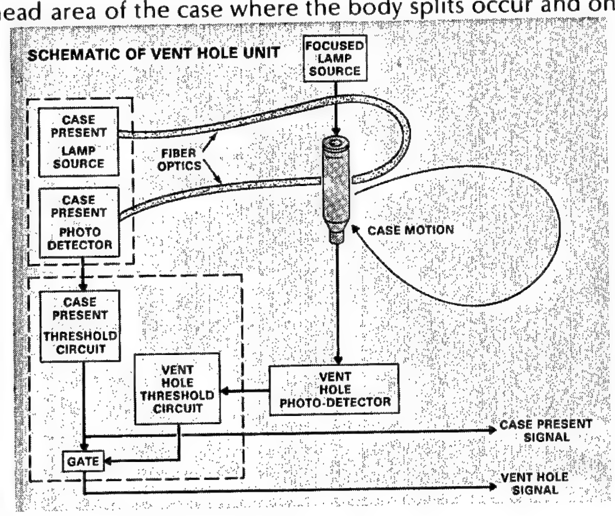

Figure 5

at the mouth area to ensure reliable detection of tight folds. Figure 7 is a conceptual design of the eddy current flaw monitor.

Out of Range Monitor

Grossly defective cases must not even enter the system, lest they become jammed and cause serious damage. Cases which are improperly trimmed may be too long and those with damaged mouths may be too short. Such conditions will be detected optically by an out of range monitor and rejected before they enter the respacer. Dimensions outside a ±30 mil window will be rejected. Figure 8 is a conceptual drawing of the out of range monitor.

Materials Handling

Handling of parts in and out of the inspection module and between inspection wheels is fully automated. The materials handling equipment includes all of the hardware to interface with the cartridge case production line, a means for holding and positioning cartridge cases in support of the various measurement monitors, provision for unacceptable cartridge case reject, and calibrated sample insertion and retrieval. The inspection module, as seen in Figure 1, consists of inspection wheels interconnected by transfer/reject wheels. The interface wheel removes cases from the production line carrier chain. The entry transfer wheel transfers them to the respacer, which respaces the cases for a larger center to center spacing and transfers them to the first inspection wheel. The entry transfer wheel contains process control instrumentation consisting of a case present detector, out of range monitor, and a reject station. A case present detector is located on the respacer along with a device for automatic insertion of standard quality assurance cases.

The first inspection wheel contains the profile monitor; the next wheel in sequence is the transfer wheel, which contains a vent hole presence monitor and a process control reject station followed by a case reject verification sensor.

The second inspection wheel which follows contains the eddy current and surface flaw monitors. Attached to the second inspection wheel is an encoder that provides the timing signals for the flaw and profile monitors and reject implementation. Following this second inspection wheel is the exit interface wheel. Two process control reject stations—one for the calibrated standard cases and the other for rejected cases—and two case reject verification sensors are located on this unit.

For all the interface and inspection wheels, each functional hardware subassembly uses a standardized design concept. This approach not only simplifies design but minimizes fabrication and maintenance costs.

Data Acquisition and Control

The data acquisition module acquires measurement data from the monitors in real time. All data is received by the computer in digital form over a high speed serial data link from the measurement/eject module. A fixed format data block is received during every case to case interval. The data block contains measured values, accept/reject signals, and status information. All measured values are compared logically with high/low accept range limits for reject determination and are used for limited statistical analysis. For measurements that result in accept/reject signals, cases which are within acceptable limits pass through the test module and appear in the overall status format as an output number.

The computer responds to each data block received by transmitting a control message back to the measurement/eject module. The control message contains one bit to control the state of each reject solenoid during the next case to case interval. A confirmation bit for each reject station is checked in the data block by the computer to ascertain correct accept/reject operation and to verify the materials handling operation.

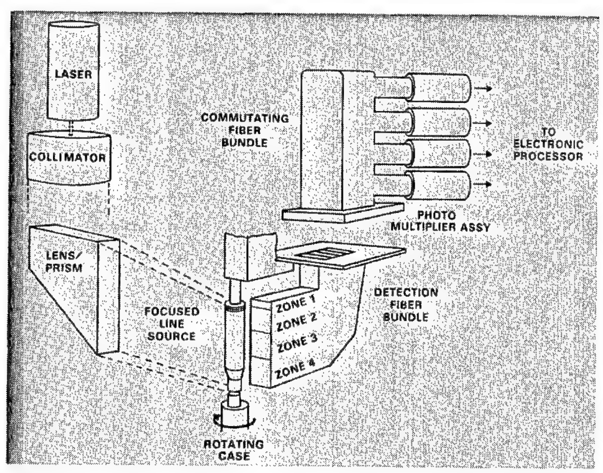

Figure 6

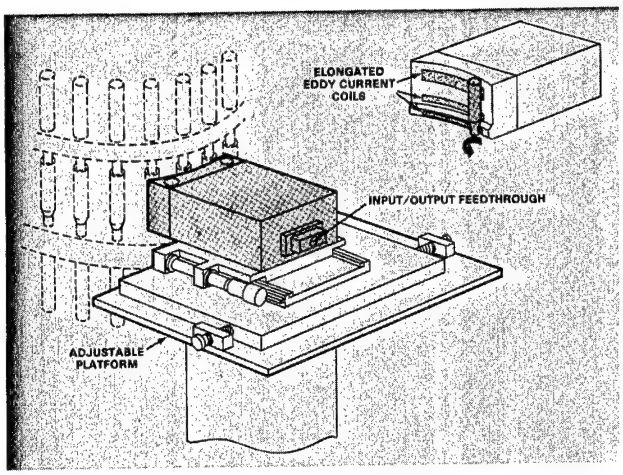

Figure 7

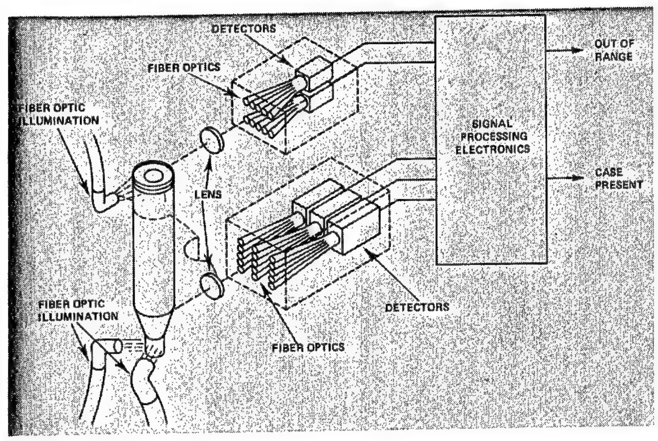

Figure 8

Data Display or Hard Copy

The principal operator communication device is a video terminal and its associated function keyboard. The operator is able to obtain data displays on video or hard copy by depressing a single function key. The rapid writing rate of the video display provides near instantaneous data presentation.

Profile measurements have quantitative inputs to the computer. If this data is averaged and output, the information is meaningful in process control operations such as tool and die wear, materials, and other manufacturing parameters.

The control functions performed by the computer system include case reject, sample case insert, sample case rejects, and special rejects.

Case Rejects Mandatory

The case reject stations are set to eject the rejected cases as they come out of each individual monitor. The first reject takes place at the entrance interface wheel and is rejected by the out of range monitor. If this reject station fails to function, the system will be automatically stopped to prevent any damage to the mechanical hardware. It is assumed that when the first reject station fails the case has been physically damaged, cannot be rejected, and presents a high likelihood of mechanical damage to the system. The remaining reject stations are located after each monitor with the philosophy that the rejected cases need to be rejected as quickly as possible to prevent damage to following instrumentation.

At the initial respacing wheel there is a standard sample case insert mechanism. This insert mechanism is utilized to insert standard samples to verify calibration of the individual monitors. After placing the standard case in the insertion tube located on the insertion mechanism, the operator can request the computer to insert the case into any of the 24 spindle positions.

Evaluation Selection Override

The special reject option provides a select feature for evaluation of the system. Under the special reject option, the operator can select any of the twenty-four tool positions for reject out of the special reject station. He can also elect to have only the good cases of a select spindle rejected from the special reject station. These capabilities allow total evaluation of any spindle position. The special reject also provides the option to request a QA sample from each of the twenty-four tool stations to be rejected at the exit wheel. An LED readout identifies the rejected case so that tool position identity can be retained. After the QA sample has been taken, the operator will have an output format listing all of the numerical data documented.

New Insulated Military Footwear A Hot Item

Improved Product, Automated Production

JOSEPH E. ASSAF is a Materials Engineer at Natick Research and Development Command. As a Project Leader, he is responsible for planning and conducting research and development projects involving rubber and rubberlike materials and ensuring that products evolving from these efforts meet military requirements. Mr. Assaf joined what was then the U.S. Army Quartermaster Research and Engineering Command at Natick in 1955 following 10 years of experience in the rubber industry. He is a registered Professional Engineer with a B.S. in Engineering Chemistry from Northeastern University. Mr. Assaf is a National Director of the Air Force Association and a member of the American Chemical Society.

Thanks to an MM&T project at Natick Research and Development Command, the military will soon have an automated capability for producing an improved insulated military boot. The manufacturing technology will also be available to industry. The new polyurethane pull-on boot is lighter than both styles of current standard rubber insulated boots of the U.S. Army, offers equal or better insulation quality, and has an inherent resistance to insulation loss. Furthermore, since the new boot has far fewer parts, automated manufacturing operations will replace the expensive hand layup procedures required with standard boots. All of this will mean an improved product for the foot soldier—produced at lower cost and with fewer production problems.

Interest Dates to World War II

The need for integrally insulated footwear for the soldier evolved during World War II. It became apparent at that time that the Army needed cold weather boots in which the insulation was an integral part of the structure. Till then, warmth was achieved through inserts, stockings, or, in some cases, overwraps. Subsequently, the Army adopted two styles of insulated boot. One was a black rubber, felt insulated boot for wet-cold climates. The other was a white rubber, felt insulated boot for dry-cold climates.

The black insulated boot was first used in the Korean conflict and proved very effective. These "Vapor Barrier" or "VB" boots are currently standard in the Army inventory. The white boot, widely known as the Army's "Mickey Mouse" boot, is also standard. Both boots use wool fleece between layers of natural rubber for insulation. The white boot has two layers providing protection down to –65 F. The black boot, with only one layer of wool, provides protection to –20 F.

Costly to Produce

Although these boots are generally quite effective, their manufacture is costly, highly laborious, and generally a major production problem. The boots include more than

forty individual parts requiring approximately sixty-five separate assembly steps. Individual components of the VB boot are shown in Figure 1. Many of the manufacturing steps require hand operations by a skilled operator. As a result, it takes 130 people and 15,000 square feet of floor space to turn out 2,000 pairs of boots a week.

Figure 1

To compound the assembly problems, the insulated boots are unique to the military. Furthermore, they are procured only sporadically to replace depleted stocks—there are no long-term production contracts. The combination of all these factors creates some real manufacturing problems.

Consider the choices of the shoe manufacturer who contracts to produce these boots. He can stop ongoing shoe manufacturing operations for the duration of the contract. Or, he can hire new, skilled personnel, who he will have to lay off at the end of the contract period. At that time, he will also have to store the equipment to await the next production run sometime in the unforeseeable future. As a result, estimated start-up costs for a given contract are as high as $400,000. These include training operators and setting up and refurbishing the necessary equipment. Considering these problems, it is not surprising that members of the footwear industry have been less than enthusiastic in bidding on contracts to manufacture insulated boots.

In addition to such manufacturing problems, the boots themselves, although effective, have certain shortcomings. For one thing, both styles are heavy. Additionally, the wool fleece insulation is only effective when dry. Because the outer natural rubber layer can be punctured, allowing moisture to reach the wool, the insulating quality can deteriorate quickly.

Polyurethane Offers Answers

With the development of injection molding technology for synthetic polymers, particularly foamed polyurethane, a lightweight insulated boot of less complex design emerged that could replace both standard boots. A boot of closed cell foam would retain its insulating characteristics despite moisture. Further protection could be provided by a puncture resistant skin. Considering these advantages, Natick developed a prototype polyurethane boot as shown in the cutaway view of Figure 2.

Figure 2

From this protytype, they launched an investigation of various synthetic materials to determine the possibility of developing an acceptable boot designed for automated manufacture. Polyurethane was finally selected as the general material type and an experimental boot was

designed. The basic design calls for a nylon sock lining over a footwear last. An upper section and an outsole of the desired foam densities are injection molded over the sock liner. An outer protective coating is added and a snow collar is attached. This collar keeps snow out of the boot and inhibits heat loss from the otherwise open top.

With this basic design set, Uniroyal was asked to investigate various polyurethane systems. The objective was to identify a formulation with optimum ratio of open to closed cells, flexibility at low temperatures, durability, and stability. Uniroyal selected polyether polyurethane based on polytetramethylene glycol (PTMG) and diphenylemethane diisocyanate (MDI) as most promising. In order to obtain the varying densities of foam needed for different portions of the boot, Lucel-4, an azo compound, was selected for foaming the upper portions of the boot. Water was selected for use as a blowing agent for the sole of the boot because, during the reaction, urea linkages are formed that impart the necessary toughness for maximum wear.

This initial work had shown that a lightweight boot, with a greatly reduced number of separate parts, could be made from synthetic materials such as polyurethane. Such a boot, as shown in Figure 3, would weigh only 29 ounces in size 10R compared to the standard vapor barrier boot weight of 46 ounces. This success with this prototype prompted additional investigations.

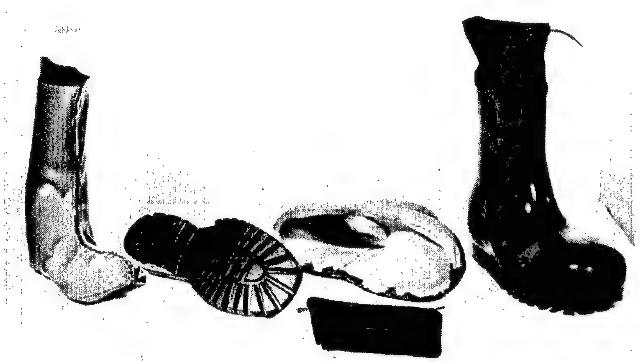

Figure 3

Insulating Properties Demonstrated

Tests showed that insulating properties of the experimental pull-on type boot were generally equivalent to or better than those of standard insulated boots (see Table 1). Insulating quality was measured in Clo values, using a copper foot. Clo units measure insulation efficiency; higher numbers indicate higher efficiency. The copper foot is a simulated human foot, designed in sections, which allows measurement of Clo values in each section simultaneously.

		Standard Boots	
Foot Sections	Lightweight Boot	Black	White
Achilles	1.65	1.57	1.54
Heel	1.91	1.80	1.93
Ankle	1.96	2.06	2.02
Tongue	1.82	1.42	1.33
Instep (Inner)	1.74	1.78	2.04
Instep (Outer)	2.02	1.88	2.37
Toecap	1.83	1.45	1.72
Foresole	1.80	2.40	2.75
Sole	2.10	2.78	3.02
Overall Clo	1.87	1.80	1.90
Weight (lb)	1.7	2.82	2.99
Weight (gr)	(779)	(1280)	(1357)

Table 1

The experimental boot was designed to match the insulating properties of the black boot. However, test results indicated that overall, its insulation quality is equivalent to that of the white insulated boot. It also was considerably lighter (Figure 4). The degree of insulation is designed to vary in different parts of the boot based on physiological requirements. This variation is achieved by using liquid foam construction techniques that control the thickness of foam produced.

Present laboratory test data on the lightweight prototype boots indicate satisfactory physical characteristics and an adequate projected service life. Insulation values were obtained before and after a 200 mile actual wear test. There was no loss in insulation properties, indicating little or no breakdown in the cell structure of the foam material during wear. These results are corroborated by results of insulation tests before and after Alaskan field testing. A report on the Alaskan test states: "The troop acceptability of the boots was favorable. The test participants liked the fit, comfort, and warmth of the boots tested." Results indicated that the outsole wear characteristics are also satisfactory.

Figure 4

Manufacturing Technology Developed

The military forces now faced a dwindling supply of insulated boots, poor contractor response to procurement requests, and a lack of industrial technology to produce the experimental boot commercially. That lack of industrial capability was obvious, since such a boot had never been produced for either the military or commercial market.

To overcome these problems, MM&T funds were solicited to attempt to develop the manufacturing capability required for producing the polyurethane boots. As a result, Natick received funds for a three-year effort with industry to develop manufacturing technology.

Using these funds, Natick has contracted with Uniroyal to purchase and set up a manufacturing system consisting of four liquid injection molding stations by the middle of 1979.

Basic Production Module Designed

The production process being set up uses the four Uniroyal designed unit stations, molds, a liquid polyurethane injector, one Ransburg electrostatic coating system, and other ancillary equipment. This setup can turn out 60 pairs of finished boots in a 5 day week, based on one shift per day. The equipment will operate more efficiently and economically over three shifts, however. The system can be expanded to any number of additional stations to meet production requirements.

The injector handles quasiprepolymer PTMG compounds and has a two and three stream capability. The equipment will independently heat or cool individual components. It will also vary liquid injection shot sizes to accommodate different boot sizes or to change component ratios for different compounds.

The process flow chart in Figure 5 shows the liquid injection molding process that is being developed. A boot socklining, made of a lightweight black urethane coated nylon tricot fabric, is hooded over the last, with the coated side out. The last is then lowered into the mold cavity and the mold is closed. The last is held at 250 F and the mold at 170 F. Polyurethane is injected into the mold cavity as defined by the bottom of the last and the top of the outsole insert. Then the soleplate (outsole portion of the mold) is raised. This forces the injected polyurethane into the space defined by the mold walls and the last sides. Foaming action of the polyurethane insures a complete fill. Following injection, the molded upper is cured for 15 minutes in the closed mold. After curing, a rubber roll buffer is used to remove flash from the upper, which is then inspected.

Two Step Sequence Used

In the remold operation, the boot upper is relasted on the heated last and damp wiped with Vythene. The fabric

tube sock is pulled over the upper, the last assembly is lowered into the mold, and the mold is closed. The polyurethane outsole compound is then injected into the cavity defined by the soleplate, rings, and the boot bottom. The soleplate is raised, closing off the injection port, and the foaming action of the polyurethane compound completes the mold fill. The boot is then cured for 15 minutes in the closed mold. After curing, the boot is buffed, weighed, and inspected.

The next step is electrostatic spray coating. In preparation, each boot is damp wiped with methylethyl ketone over the entire outside surface—with the exception of the bottom of the outsole—to remove any surface contamination. The boot is hooded over a metal support form (short last) and a vacuum formed polyethylene spray mask is placed over the bottom of the outsole. A polyurethane coating is then applied by electrostatic spraying for 12 minutes. During spraying, the metal form is grounded and the polyurethane spray is positively charged to attract the spray coating to the surface of the boot.

After coating, the boots go into a drying oven. Initially, they are air dried for 24 minutes at room temperature to allow the solvent to evaporate. They are then hot air cured for 25 minutes at 250 F. After curing, the boots are held at 160 F for 12 hours to insure complete solvent evaporation. They are then removed from the oven and cooled at room temperature for 1 hour. Finally, the boots are trimmed to the proper height (10½ in. minimum) and moved to the finishing area where the collar is attached.

New Directions

The lightweight insulated boot was one of the first stock funded items approved and funded as an MM&T project. This was an unusual MM&T program in that the technology involved dictated not only the manufacturing methods but also the basic design of the boot. Some of the design changes, such as the elimination of lacing and the choice of a pull-on type boot, were necessary for optimum compatibility with the molding process. The program was successful in meeting its principal objectives to reduce the number of hand operations and provide a lighter product, with inherent resistance to sudden insulation loss.

Completion of the project will provide the Government with an automated industrial capability for producing an improved insulated boot. End results will be a prototype line, specifications for the equipment and the process, and quality assurance data that will become part of an end item specification. This manufacturing technology all will be available to industry.

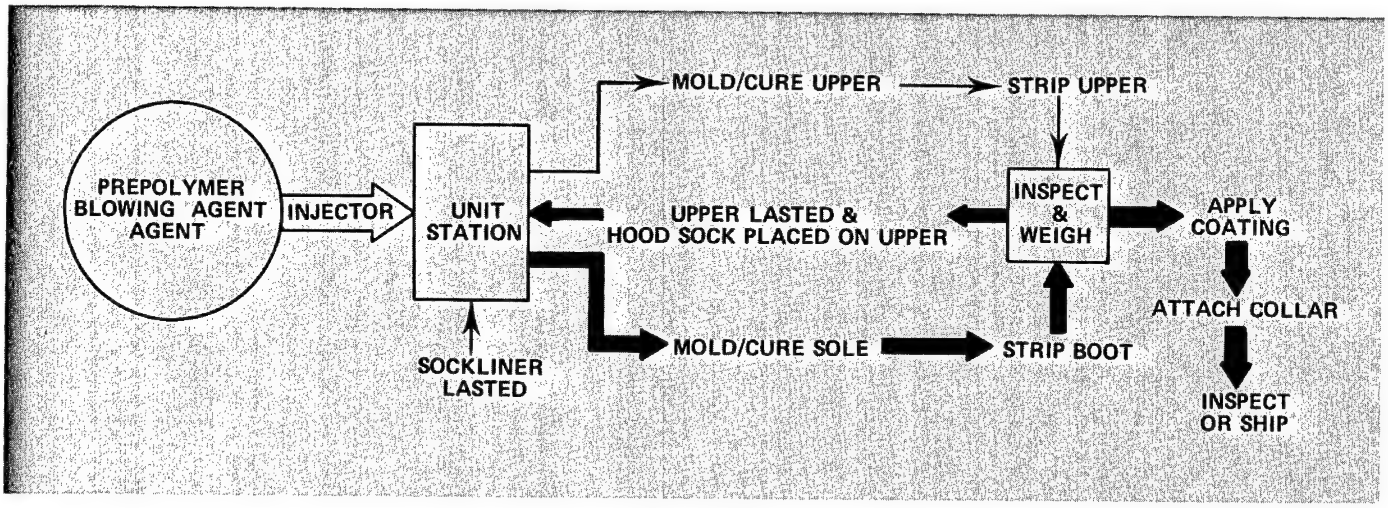

Figure 5

X-Ray Checkout For Propellants

In-Process Analysis To Slash Costs

BERNARD J. ALLEY is Group Leader for Analytical and Physical Chemistry, Army Propulsion Directorate, Technology Laboratory, MIRADCOM. He has had 22 years of experience in developing new and improved solid propellants for Army missile systems and in applying analytical and physical chemistry techniques to propellants and propellant ingredients. He received a B.S. in Chemistry from The Citadel in 1950 and an M.S. in Physical Chemistry from The University of North Carolina in 1952. In 1963, he received a Special Act or Service Award for propellant binder investigations made as a member of a special task force and in 1970 was presented the Scientific and Engineering Achievement Award for codevelopment of a new class of ballistic modifiers for double base propellants. Mr. Alley has more than fifty technical publications to his credit and holds ten patents. He is a member of the Chemical Subgroup of the Technical Working Group—Test and Evaluation Methods for Materials Testing Technology. He served for 6 years as Chairman of the Joint Army, Navy, NASA, and Air Force (JANNAF) Propellant Characterization Working Group.

An X-ray fluorescence analysis technique that monitors both composition and particle size during solid composite propellant manufacture has been developed during an MTT program at the Missile Research and Development Command (MIRADCOM). This nondestructive technique is very rapid, precise, and accurate. Its use can prevent the costly delays in motor loading encountered with present methods. The analysis can also be used to predict propellant burning rate and thus to reduce the number of ballistic test motors needed to qualify a propellant batch. All of which represents a very significant potential cost savings for most missile systems.

Solid Propellants Widely Used

Solid composite propellants are used in the propulsion systems of a large number of Army rockets and missiles. These propellants are a mix of various organic and inorganic liquids and solids and include a polymeric binder, an oxidizer such as ammonium perchlorate, and a fuel such as aluminum powder. Additives are often incorporated to modify or improve ballistic, mechanical, and rheological properties.

Performance requirements for specific missiles are met by varying propellant composition and particle size distribution, both of which affect propellant properties. (The particle size of ammonium perchlorate is particularly important.) Thus, these two factors must be closely controlled, preferably by monitoring during propellant manufacture. Current chemical analysis procedures, however, are too slow and imprecise for most composite propellant manufacturing applications.

X-ray fluorescence spectrometry, on the other hand, has features that make it especially well suited for composite propellant analysis and control. It can be used to determine both propellant ingredient percentages and average particle size of solids, either separately or simultaneously. Typical multicomponent propellant analysis for multiple samples takes less than 30 minutes and offers both precision and accuracy of 99 percent or better. Moreover, the method can be applied satisfactorily to both cured and uncured propellants.

Because it is based on elemental emission, however, the method is limited to propellant ingredients that contain elements of Atomic Number 11 (sodium) and higher. This precludes determination of strictly organic ingredients. In applying the method, a calibration must be established for each type of propellant to be analyzed using an appropriate mathematical or statistical model.

MIRADCOM Development

Because of its outstanding features, MIRADCOM launched an MTT program to develop the X-ray fluoresecence method for application to a manufacturing process. This successful development followed several years of research with the method within the Army Propulsion Directorate. The sequence of events in application of the method to propellant manufacture is depicted in Figure 1.

Propellants are formulated as usual in a batch process using a double sigma blade vertical mixer. After the propellant is mixed, the composition of slurry samples is analyzed by automated wavelength dispersive X-ray spectrometry. An operator loads the samples and initiates the analysis. The computer controls the spectrometer and calculates ingredient percentages using measured characteristic X-ray emission line intensities and previously established calibration response functions.

Using the X-ray analysis results and a joint confidence interval statistical test, the nominal propellant composition is accepted if it falls within a specified confidence region—e.g., 95 percent. Propellants meeting the criterion can be cast into motors without delay. A substandard propellant will either be corrected and reanalyzed or discarded to prevent costly motor loadings. During these operations, the X-ray spectrometer, propellant mixers, and casting apparatus are separated by appropriate barriers for practical and safety reasons.

X-Ray Fluorescence Principle

The principle of the wavelength dispersive X-ray fluorescence spectrometric method used is illustrated in Figure 2. Primary rays from the X-ray tube irradiate the surface of an uncured propellant sample which is supported by a thin, transparent film. This irradiation excites elements in the propellant surface, which then give off their characteristic fluorescent radiation. The fluorescent radiation is collimated and dispersed in accordance with the BRAGG equation by an analyzing crystal having a fixed interplanar d-spacing. With the analyzing crystal and detector rotating in the same plane, the detector—in combination with suitable electronics—measures the fluorescent emission line intensities. These intensities are then related to propellant ingredient percentages by a suitable calibration procedure that accounts for interelement or matrix effects.

Because most of the propellant ingredients analyzed contain light elements that produce relatively long wavelength emission lines, optimum spectrometric components and operating conditions for light element analysis

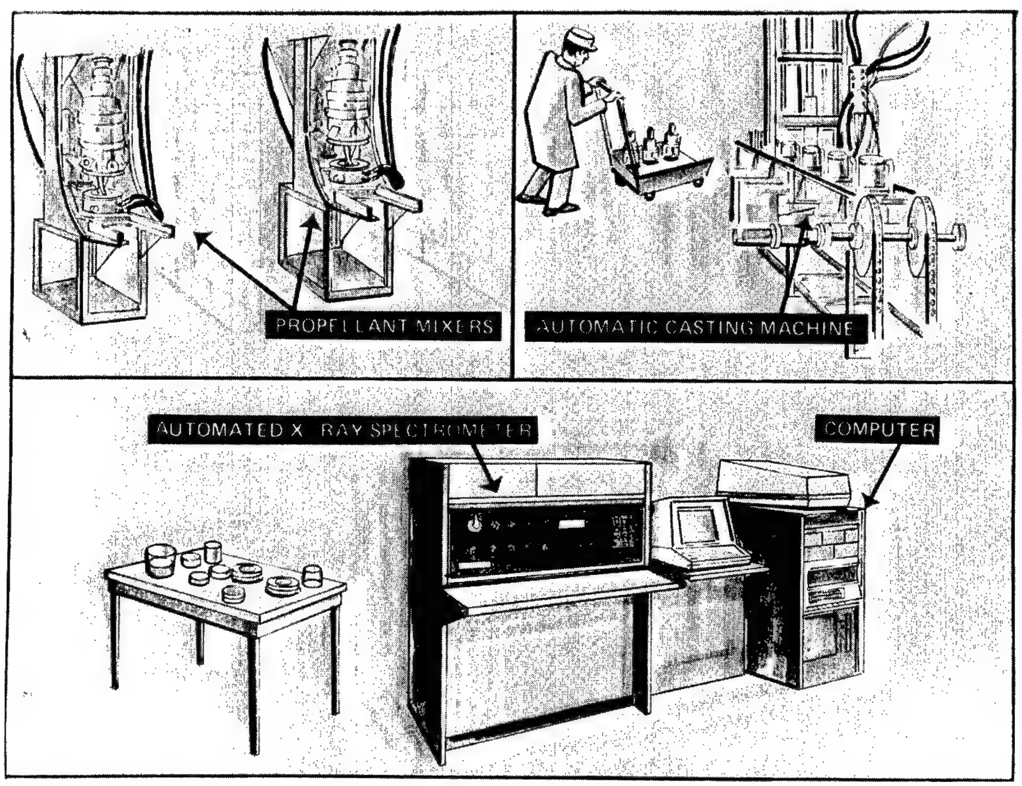

Figure 1

are used. This requires

- An X-ray tube with a light element target such as chromium
- Coarse, low resolution collimators
- Analyzing crystals with large interplanar d-spacings
- A flow proportional detector
- An evacuated or helium flushed optical path.

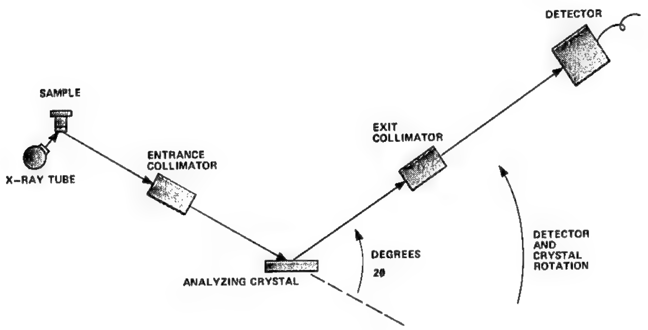

Figure 2

Determining Composition

Although X-ray fluorescence analysis can determine X-ray emission line intensities very precisely, accurate elemental determinations are often difficult because of sample matrix or interelemental effects. Thus, mathematical calibration procedures must be employed to relate elemental emission line intensities and propellant composition and to accurately compensate for interelemental effects. Multiple linear regression analysis provides an effective, practical calibration approach to this problem.

In this approach, a series of calibration mixtures are prepared and analyzed for the least squares estimation of coefficients in the multiple regression equations. Proper selection of calibration mixtures is critical to insure that the coefficients are accurately determined and that the number of mixtures is minimized. Consequently, the calibration mixtures are selected and prepared in accordance with a suitable statistical experimental design. This generally eliminates the undesirable confounding of effects and high degree of correlation among ingredient percentages. Depending on the particular calibration situation, one may use factorial and fractional factorial designs, central composite designs, simplex lattice designs, simplex lattice designs with reference mixtures, or extreme vertices designs. Factorial and fractional factorial designs were found to be satisfactory during this MTT effort.

System Accuracy Demonstrated

The accuracy of this X-ray fluorescence method in determining ingredient percentages in uncured propellant is illustrated in Table 1 for four ingredients in uncured polybutadiene acrylic acid (PBAA) type propellants. Four replicate samples were analyzed and averaged from each of five different propellant batches. The total analysis time for each batch was less than 30 minutes. The calibration mixtures for establishing the partial regression coefficients were selected using a half fraction of a 2^4 factorial design.

Batch	Ferric Oxide		Ammonium Perchlorate		PBAA Polymer		Aluminum	
	Weight, %	Error	Weight, %	Error	Weight, %	Error	Weight, %	Error
1	0.5549	0.0035	70.16	-0.02	12.72	0.19	15.13	0.09
2	0.4400	-0.0026	68.41	-0.43	14.40	0.14	14.98	0.23
3	0.5618	-0.0013	67.52	0.01	12.79	0	17.29	-0.10
4	0.5650	0.0026	67.56	0.04	14.69	-0.14	15.04	-0.30
5	0.4531	0.0026	65.94	-0.16	14.76	0.24	16.96	-0.07

Table 1

Typical precision for replicate sample analyses of PBAA propellants is shown in Table 2. The estimated relative standard deviations (sampling errors) for individual sample determinations are based on 24 degrees of freedom for uncured samples and 20 degrees of freedom for cured samples. The repeatability error is less than 1 percent relative for all ingredients except cured PBAA propellant.

Ingredient	Sampling Error: Uncured Propellant	Sampling Error: Cured Propellant
Ferric Oxide	0.76	0.84
Ammonium Perchlorate	0.79	0.61
PBAA Polymer	0.75	1.32
Aluminum	0.86	0.73

Table 2

Measuring Particle Size

The X-ray fluorescence method demonstrated its ability to rapidly measure the average particle size of solid propellants—notably ammonium perchlorate and aluminum—in situ. The ability to measure variations in ammonium perchlorate particle size is particularly important.

The size of these particles usually has a pronounced effect on propellant burning rate, and uncontrolled grinding or agglomeration during propellant manufacture can cause wide variations.

During this development effort, a linear relationship was seen between the weight mean diameters of ammonium perchlorate and aluminum and chlorine $K\varphi$ and aluminum $K\varphi$ radiations, respectively. Furthermore, linear relationships between these radiations and variations in bimodal blends of either ammonium perchlorate or aluminum were demonstrated.

An example of this relationship for variations in a bimodal blend of nominal 20 micrometer and 200 micrometer ammonium perchlorate is shown in Figure 3. When the aluminum particle size and ingredient percentages are held constant, the chlorine $K\varphi$ intensity increases as the ammonium perchlorate weight mean diameter decreases. The chlorine $K\varphi$ intensity also increases when the aluminum weight mean diameter increases. The aluminum $K\varphi$ radiation is similarly affected by aluminum and ammonium perchlorate particle size changes. In fact, the aluminum $K\varphi$ radiation is more sensitive to ammonium perchlorate particle size changes than the chlorine $K\varphi$ radiation, and therefore is the radiation element chosen for ammonium perchlorate particle size measurements. Ammonium perchlorate and aluminum particle size changes are quantified using calibration procedures similar to those used for the ingredient concentration determinations.

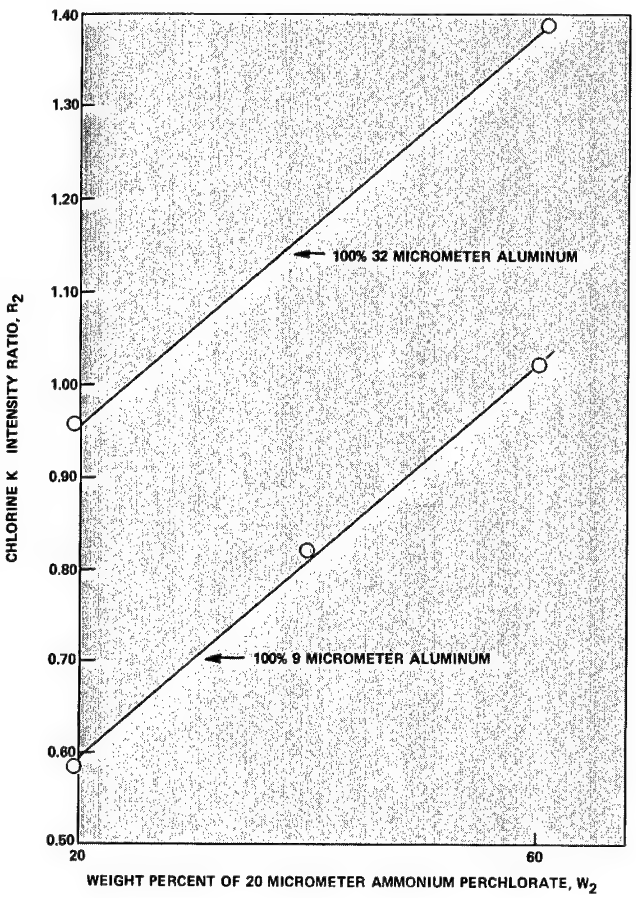

Figure 3

Potential Implementation

The X-ray fluorescence method described here has potential application to all types of solid composite propellants used in Army missile systems. It appears to be especially attractive for potentially high production rate systems, such as VIPER and the General Support Rocket System (GSRS). The ability to detect and quantify in situ the agglomeration of ultrafine ammonium perchlorate is a very valuable feature for high burning rate propellant applications. The X-ray fluorescence method measures most compositional parameters that correlate with propellant burning rate and has, in several cases, been able to accurately predict propellant burning rate. If it were used in this way, the number of ballistic test motors required to qualify propellant batches for particular missile systems could be reduced, dramatically reducing propellant production costs.

X-Ray Scintillation Ensures Fuze Quality

Density, Homogeneity of Foam Controlled

X-ray scintillation inspection techniques developed at Harry Diamond Laboratories (HDL) are now being used to maintain process control while injecting artillery fuzes with polyurethane foam. The technique was used in M728 proximity fuze production at Raytheon in Bristol, Tennessee. Another system was installed at the M732 proximity fuze production facilities at Danville, New Jersey, and placed in operation in the Summer of 1978.

During studies at HDL, X-ray scintillation was shown to offer several advantages over other applicable techniques for detecting voids in foam. HDL is now evaluating other possible uses for this rapid, low cost technique, which should be adaptable to many in-process inspection operations.

ROBERT T. NIEMEYER is Quality Assurance Specialist for the Engineering and Product Assurance Division of the Harry Diamond Laboratories. He has been involved in artillery and missile fuze development, engineering, and production testing throughout his 27 years of government service. He initiated and developed the first testing studies on radiographic detection of potting voids in electronic fuzes at HDL in 1973 and has since been the primary proponent for adopting X-ray scanning as a nondestructive testing method for the M728 and M732 fuze production programs. Mr. Niemeyer not only has been responsible for developing HDL's radiographic inspection techniques but also for setting development and production acceptance X-ray requirements for a number of artillery fuzes, fuze components, and other related materiel. He is a member of the American Society for Nondestructive Testing—Chesapeake Bay Chapter—and the Washington Chapter of the American Defense Preparedness Association.

The present application arose because many of the electronic artillery, missile, and mortar fuzes developed at HDL use a polyurethane foam potting. This potting supports and protects delicate fuze electronic components from the severe shock encountered by the fuzes when a weapon is fired. The foam can provide the necessary support without affecting electrical functions of the fuze.

Foam Characteristics Vital

To do this, however, the cured foam must have the proper density and homogeneity. A density of 18 to 25 lb/ft^3 is necessary in a cannon firing environment, and the subassembly cavity must be entirely filled without air pockets, voids, or improperly mixed solid potting.

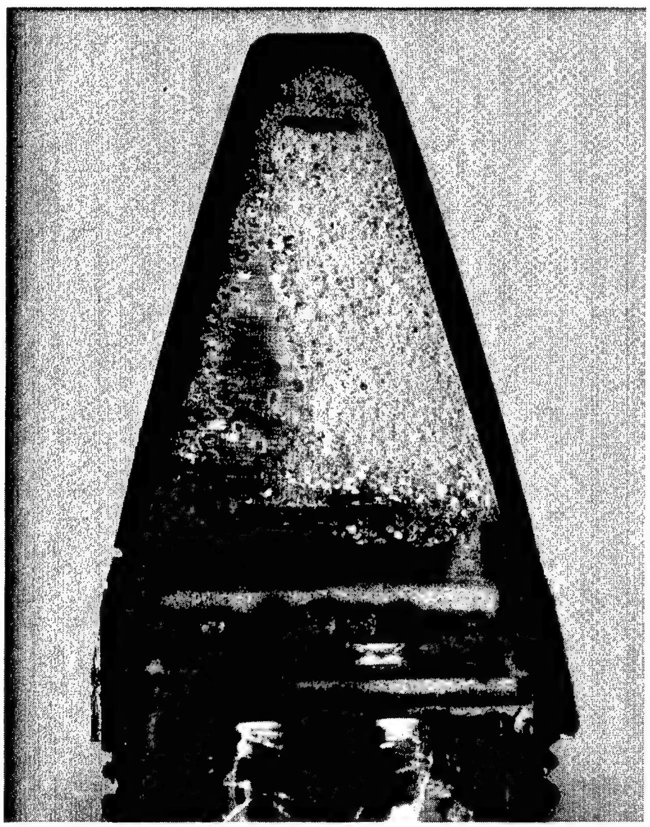

Figure 1

Figure 1 is a cutaway view of an M732 oscillator assembly containing improperly mixed solid potting. Dense, brittle potting is seen on one side of the oscillator section and extremely low density potting fill is seen throughout the remaining area. In comparison, note the regularity in foam density in the subsequently filled amplifier cavity, which appears immediately below the oscillator section. Close process control can prevent such problems by insuring that the potting is correctly formulated, injected, and cured and that proper temperature is maintained.

Because of this need to improve process control, HDL conducted a study in 1973 to determine a means for rapid and reliable detection of voids in foam potted fuze assemblies. The methods evaluated included neutron and X-ray radiographic techniques, ultrasonics, holographic nondestructive testing, television X-ray imaging, and X-ray scintillation gaging. Although other techniques produced satisfactory results, the X-ray scintillation gaging technique was adopted because it was inexpensive, quite flexible, and readily available. In addition, the method—once adjusted and calibrated—required fewer operator skills and could easily be automated to rapidly detect improperly foamed assemblies. It also made interpretation of results less subjective.

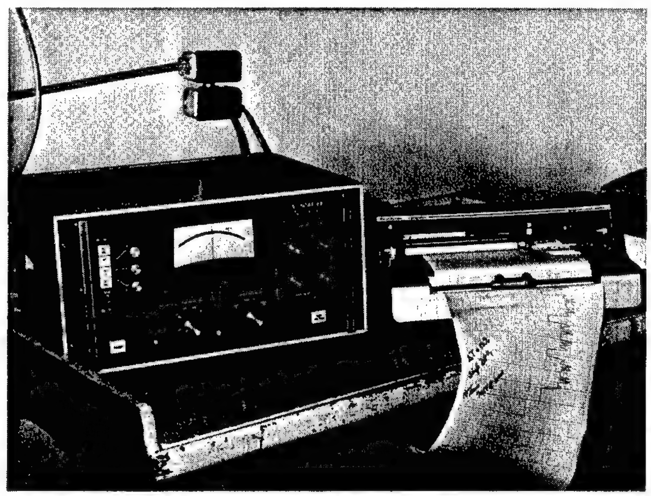

Figure 2

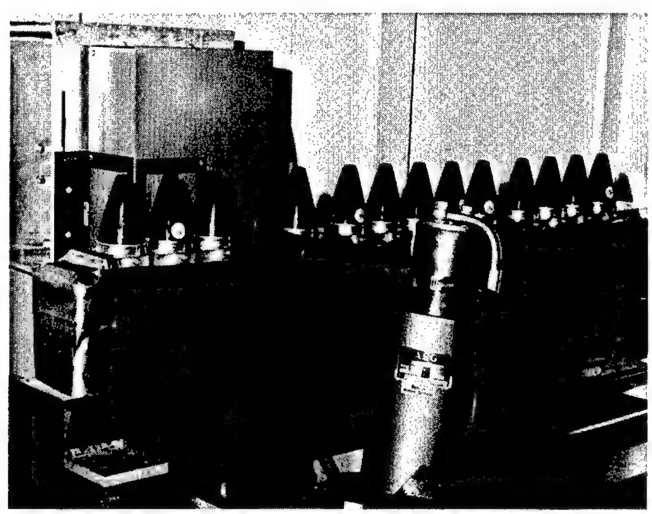

Figure 3

Figures 2 and 3 illustrate the off-line X-ray scintillation scanning setup used in the M728 facility. Figure 2 shows the amplifier control and chart recorder. The 15 station positioner is shown in Figure 3. In the foreground is the water-cooled 160 kV X-ray tube head source. The positioner is pneumatically actuated through interlocking safety circuits in the control console. The detector system senses changes in X-ray transmission and converts the beam to an electrical signal. The amplifier control unit processes this signal and displays the electronic image as an ink signature trace on the chart recorder.

Detects Voids, Measures Density

A chart display is shown in Figure 4. From left to right, this chart depicts signatures of a fully foamed unit, a non-foamed (empty) unit, a typical acceptable production sample, an M728 oscillator assembly containing a void, and another acceptable production sample. The defective sample is clearly discernible from acceptable units.

Once the equipment is calibrated, the scanning rate for inspection can be adjusted to inspect from 15 to 20 of the 2 inch wide assemblies per minute. Nonconforming assemblies can be immediately segregated and the inspection results reported to the assembly line foam station operator.

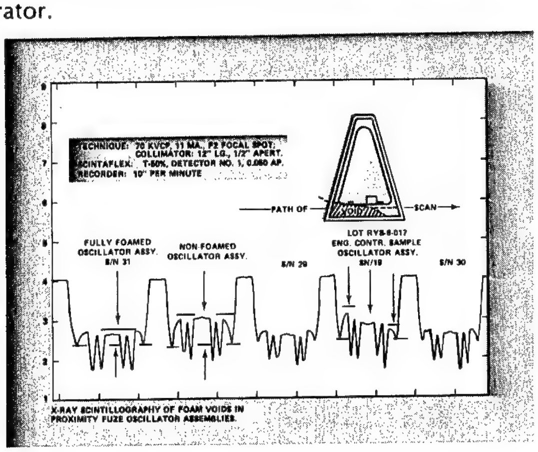

Figure 4

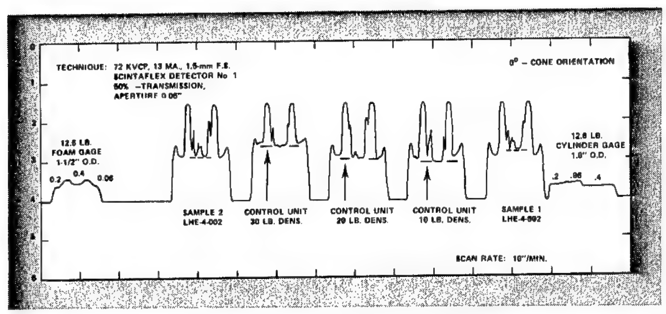

Figure 5

The system is also sensitive to foam density, as shown in Figure 5. This chart illustrates the capability to detect the relatively small changes in radiographic contrast between 10, 20, and 30 lb density foam potting in M732 fuze oscillator assemblies. This sensitivity further demonstrates the utility of the system for providing quick feedback information for process control applications—information not ordinarily acquired through X-ray film processing and analysis.

Further Applications Sought

HDL is now evaluating possible new applications for X-ray scintillation inspection in fuze production. These include inspection of

- The fuze lock ring position after assembly
- The condition of the power supply cell
- The electronic timer soldering at blind eyelet feedthroughs
- The safe condition characteristics of the safe and arming device.

Other applications are foreseen in cases where high volume production rates and lower critical inspection costs are needed to maintain high reliability in stockpile weaponry.

USArmy

ManTechJournal

Casting On The Increase

Volume 3/Number3/1978

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US Army ManTech Journal

Contents

ABOUT THE COVER:

Rock Island Arsenal demilling operation is seen in this spectacular photograph by RIA staff photographer Larry Wisenburg. Obsolete weapons are melted down to be poured into ingots for resale as high grade unclassified steel to private industry. Workers wear protective clothing of aluminum covered light canvas and protective face shields. This operation is representative of one of the economies practiced at the Army's major casting facility, where researchers are heavily engaged in programs on casting.

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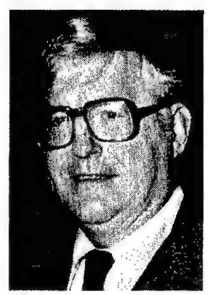
Comments by the Editor



DR. JOHN J. BURKE

The Department of Defense and industry worldwide are following the same course in respect to their approach to the future of casting. All are convinced that this method of fabrication is going to have an increasingly greater impact on our lives as new material utilization and greater precision and complexity characterize the components of new designs for machines and machinery. Thinner walls, lighter weight, greater strength, and increased complexity of design all are concomitant with a greater use of automated control by manufacturing engineers as they strive to achieve greater efficiency in the expenditure of fuel, materials, and funds in the production of our every nation's needs.

The Casting Technology Workshop sponsored last year by the Metals Subcommittee of the Manufacturing Technology Advisory Group reflects both government's and industry's recognition of the importance of the casting technique to efficient production of our military and civilian materiel. That meeting represented the manifestation of an untiring dedication by our responsible industrial and military manufacturing leaders to the need for a coordinated effort to develop these new casting techniques, in order to make the most of our national resources. Continual review of these developments and coordination of future R&D efforts will ensure the achievement of MTAG goals in the most effective manner.

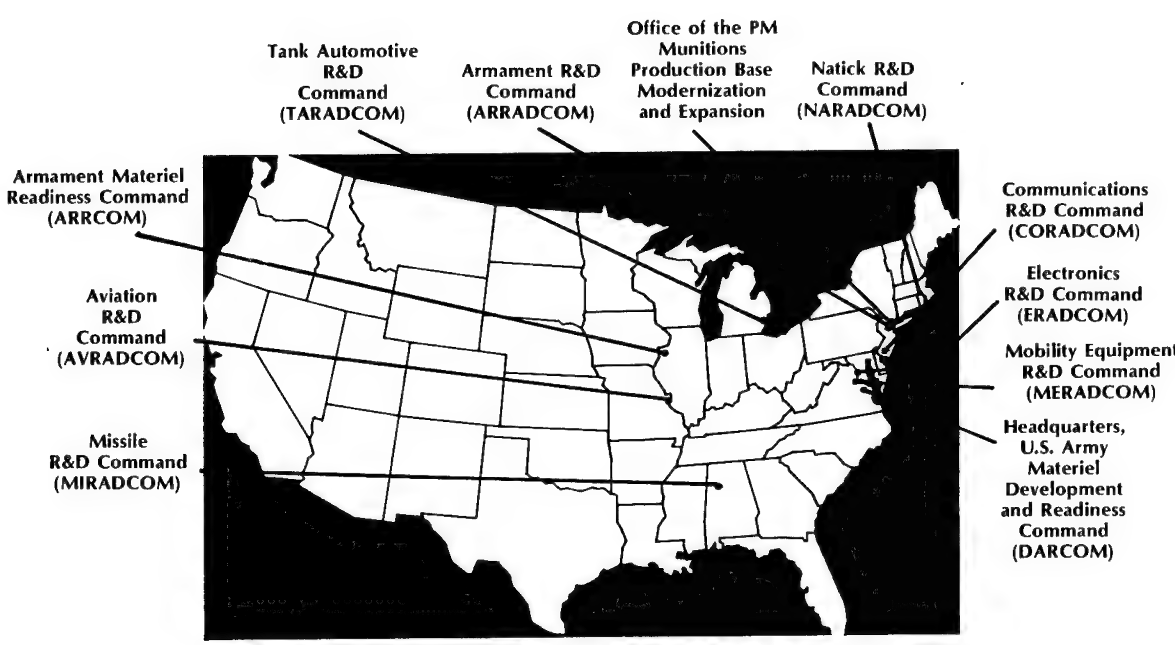
This issue of the Army ManTech Journal contains several enlightening articles pertaining to these casting challenges, in keeping with the scheduling of the process for a major part of the DOD investment toward improved production capability and lowered costs. Many components compel engineers to specify casting as the only feasible means of fabrication in order to meet the design requirements for complexity of form, near net shape, materials that are difficult to work with, and an ultimate part that will have a long, reliable service life while remaining within cost restrictions.

Related to the technological aspect of the challenge is that of finding the best supplier for a particular task, as so superbly outlined in this issue by the article from Don Crewdson and Fred Gundlach of General Electric. GE's approach to the problem of finding the "right" casting supplier may be one that many other firms want to follow as the casting industry becomes more specialized and suppliers develop more unique (or even proprietary) capabilities. Most large contractors for the DOD already have made con-

siderable mention of this problem of knowing where and to whom to go with a particularly challenging casting problem, and we hope this unusual treatment of the subject will provide new insight for them.

The next issue of the Army ManTech Journal will feature composites as a main theme, rather than joining as stated in previous issues of the magazine. Joining will be the topic of the first issue for the 1979 volume, with composites finishing up the 1978 volume of publications. Composites represent one of the most rapidly developing technologies in manufacturing, and it appears this last issue of the 1978 series will contain information of wide interest to our readers.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



DOD Pushes Improved Casting Technology

Coordinated Industry/Military Effort

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Casting is becoming an increasingly important technique in the manufacture of defense systems. The improvements in casting technology growing from this increased emphasis offer important advantages throughout industry, including the civilian sector. Recognizing casting as an economical way to manufacture intricate components, the Department of Defense has taken a strong interest in upgrading casting capabilities. These efforts are aimed both at product improvement and lower costs.

A very productive workshop on casting technology—held at Arlington, Texas, in March, 1978—emphasized this interest while providing guidelines for future research. As

a result of this joint Industry/DOD effort, all three services are taking positive action toward improving casting technology. And, equally important, these programs are being carefully coordinated.

Programs now under way promise increased design flexibility and lower production costs. As a result of these programs, more castings will be used in DOD systems, particularly those systems using superalloys, titanium, and aluminum. Industry is already deeply involved in the DOD effort through their workshop input and participation in the ongoing programs. Thus, the burgeoning technology should be readily applicable to nondefense production as well.

Even before the Casting Technology Workshop, the Department of Defense was a leader in developing casting technology through its Manufacturing Technology (MT) Program. As a part of the MT Program the Metals Subcommittee of the Manufacturing Technology Advisory Group (MTAG) coordinates Army, Navy, and Air Force MT programs in order to avoid duplication of effort. It was this subcommittee that sponsored the Casting Technology Workshop.

DOD Gets Industry Views

The workshop format encouraged open discussion of where DOD stood and where it would be going in developing casting technology and the use of castings in DOD systems. The workshop objectives were to

- Review the industry state of the art
- Review selected current and future DOD efforts
- Promote use of castings in advanced systems
- Coordinate the views of producers, designers, and materials engineers
- Identify the direction of future DOD efforts.

To accomplish these objectives, the workshop began with a review of the current state of the art in casting of aluminum, steel, titanium, and superalloys. These are the four predominant materials used in engines, airframes, ships, and land vehicles. These systems were covered in discussions of design requirements following the initial review.

SUMMARY OF FY 79 METALS PROGRAM		
	Number of Projects	Value in Thousands
Army	57	17,312
Navy	25	6,869
Air Force	50	15,950
Total	132	40,131

Table 1

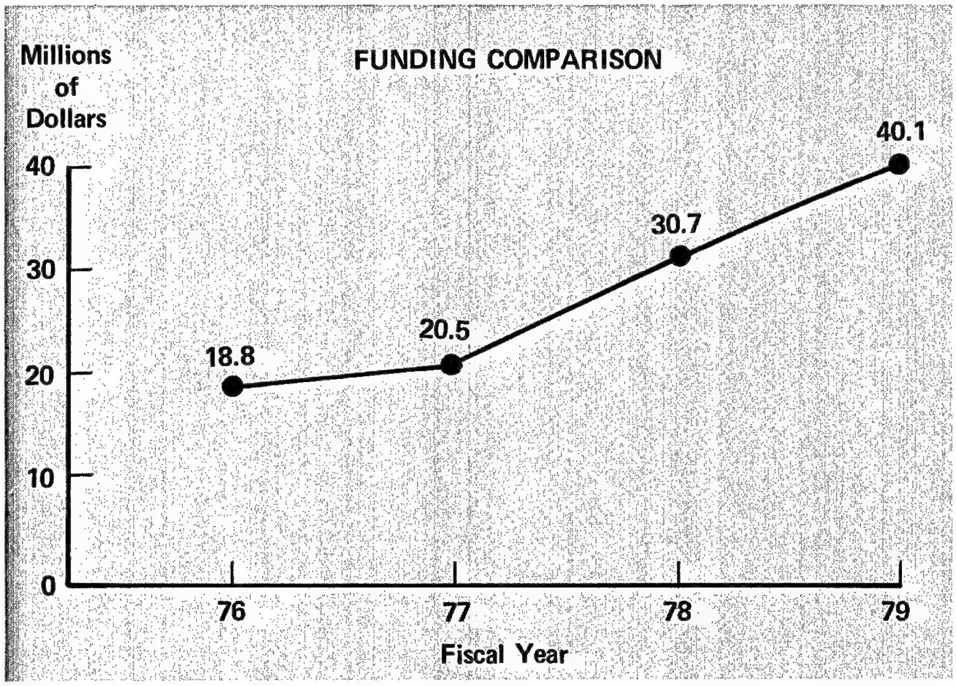


Figure 1

After these two sessions, Army, Navy, and Air Force representatives reviewed active and planned casting technology projects of their respective service. Then participants were assigned to one of four panel sessions, covering each of the four materials. These panel sessions brought forth industry's views on DOD's casting technology efforts.

From the panel discussions, specific goals emerged for each material:

- Superalloys—establish the technology for premium quality castings.
- Aluminum—introduce aluminum castings into primary airframe structures.
- Titanium—introduce titanium castings into turbine engine rotating components and primary airframe structures.

These goals are now being aggressively pursued in coordinated efforts of all three services. As for steel, it was decided that its use in DOD systems should be limited.

Prime Technical Issues Identified

Most of the technical issues raised by industry representatives fall into three major areas where improvements are needed—(1) design and processing data base, (2) process technology, and (3) nondestructive evaluation techniques.

All of the panels pointed to large gaps in the design and processing data base. Specifically, the titanium panel recommended that DOD establish both specification and radiographic standards for Ti-6Al-4V. In response, the Air Force has issued a draft specification for review and comment and the Army has initiated action to establish radiographic standards.

The titanium panel also pointed out the need for a design handbook for titanium castings. The Army is now considering funding a project to develop such a handbook. The aluminum panel saw a need for data on aluminum casting allowables. In response, the Air Force is planning to examine processing effects on these allowables.

Recommendations by all of the panels dealt with improving casting process technology. Some of the recommended areas for project work are

- Refining parameters for hot isostatic pressing of castings in terms of alloys and methods.
- Establishing the feasibility of rheocasting superalloys.
- Establishing the processing parameters for premium superalloy castings.

Programs in most recommended areas already have been budgeted by the three services. An exception is premium superalloy casting, where the Navy and Air Force have created a program to establish the necessary processing parameters. At the time this article was prepared, it appeared very likely that these two services would jointly fund that project.

FY 79 METALS PROGRAM DISTRIBUTION Commodity/Service				
	Army	Navy	Air Force	Total
Aircraft	9.2	3.8	38.0	51.0
Missiles	1.7	–	–	1.7
Ships	–	13.2	–	13.2
Weapons	7.0	–	–	7.0
Ammunition	12.6	0.2	1.7	14.5
Land Vehicles	11.8	–	–	11.8
Support Equipment	0.8	–	–	0.8
Total	43.1	17.2	39.7	100.0

Table 2

Inadequate nondestructive evaluation (NDE) techniques were a major issue at an MTAG Joining Technology Workshop as well as at the casting workshop. Industry participants observed that NDE techniques tend to lag behind materials and processing advances. This lag often can hinder full utilization of the advances. The Metals Subcommittee is inviting the MTAG Test and Inspection Subcommittee to participate in planning and executing future DOD/Industry reviews of NDE. In this way, and also through joint subcommittee meetings, the Metals Subcommittee hopes to influence the direction of NDE technology advances.

Part of Larger Effort

The workshop was not an isolated DOD effort. Through MTAG, casting is an important part of DOD's MT effort. MTAG's coordination of manufacturing technology efforts among the three services seeks to ensure optimum achievement, prevent duplication, and promote maximum utilization of improved manufacturing technology. Each service plans and executes a Manufacturing Technology Program designed to meet its own requirements. MTAG tries to mesh these various projects into a coordinated program that still meets the individual requirements of each service.

MTAG operates through a two level structure. On top, the Executive Committee is made up of senior managers from DOD and the three services. Six subcommittees—Metals, Nonmetals, Electronics, CAD/CAM, Munitions, and Test and Inspection—report to the Executive Committee. Subcommittee members represent the project management level of the three services and NASA. The Metals Subcommittee has 32 members representing 23 organizational elements.

Intercommunication, Frugality The Objectives

Although overall objectives are basically the same, each subcommittee has developed its own operating style. The Metals Subcommittee directs its efforts toward providing a forum for the exchange of technical information and ideas dealing with advanced metals processing and toward obtaining the maximum utilization of funds allocated to the advancement of metals processing.

This general objective has evolved from 4 years of subcommittee effort. In 1974, when the subcommittee was first formed, its primary objective was to eliminate duplication of effort among the services. Now, the formation of jointly funded efforts is of equal importance. The Casting Technology Workshop represented a further step in expanding the subcommittee's scope. In the past, the subcommittee had concentrated on specific project work that did not require the involvement of industry. Through the workshop, the subcommittee attempted to influence the direction of programs by asking industry to critique current and planned efforts.

Why Casting?

To explain why so much effort is concentrated on casting requires an overview of the MTAG Metals Program. Table 1 summarizes the number of projects in the FY79 Metals

FY 79 METALS PROGRAM DISTRIBUTION
Technology/Service

	Army	Navy	Air Force	Total
Forging	9.7	1.2	4.6	15.5
Casting	8.4	2.5	3.8	14.7
Powder Metallurgy	4.2	1.2	4.7	10.1
Extrusion & Rolling	4.7	0.4	3.1	8.2
Metal Removal	7.2	0.1	6.1	13.4
Joining	4.9	7.9	6.9	19.7
Surface Treatment	2.7	1.6	3.0	7.3
Forming	—	—	4.0	4.0
Other	1.3	2.3	3.5	7.1
Total	43.1	17.2	39.7	100.0

Table 3

Program and their dollar value by service. When these figures were calculated in June, 1977, there were 132 projects worth $40 million. These figures are now significantly lower since the Air Force reduced funding of its MT programs.

Figure 1 shows the growth of the Metals Program over the past four fiscal years. Although the Air Force reduction will lower the FY79 figure, the FY80 program is expected to reflect the $10 million per year growth shown in this chart.

To get a better handle on where the dollars go, we need to consider the three major components in the Metals Program—(1) the technology being addressed, (2) the commodity being supported, and (3) the service undertaking the effort. The primary technologies are forging, casting, powder metallurgy, extrusion and rolling, metal removal, joining, surface treatment, and forming. The commodities supported are aircraft, missiles, ships, weapons, ammunition, land vehicles, and support equipment. Table 2 shows the percentage of funds allocated to each commodity by each service. Note that aircraft projects absorb more than 50 percent of total funding.

Casting Future Bright

Table 3 shows the percentage distribution of funds to each of the primary technologies by each of the services. Casting consumes 15 percent of total program funding, with each service contributing significantly. An analysis of the services' Five Year Plans (Figure 2) shows that funds for forging will decrease in the future, so joining and casting emerge as the two most important manufacturing technology areas based on funding. Therefore, workshops were scheduled to address problems in these two areas.

SUMMARY OF FIVE YEAR PLAN

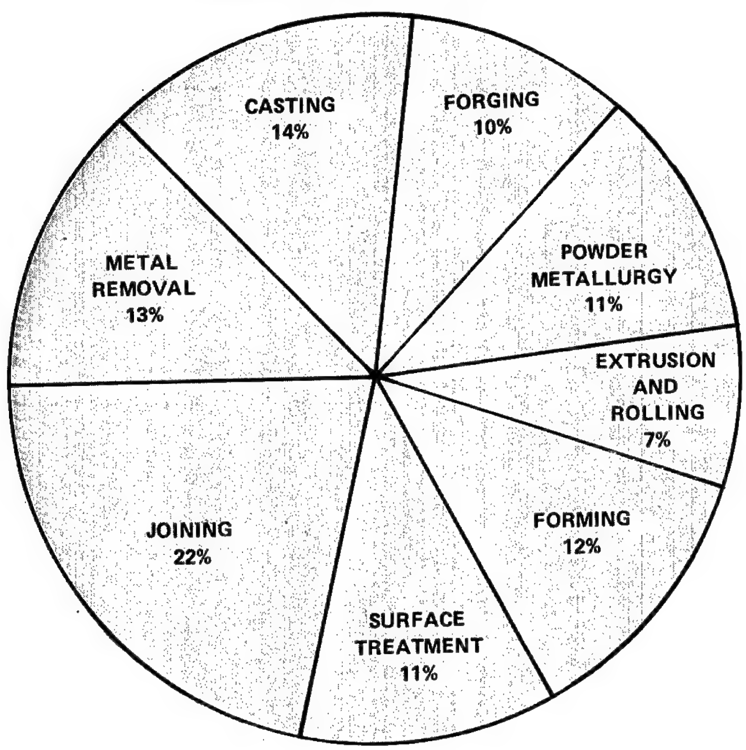


Figure 2

FY 79 METALS PROGRAM DISTRIBUTION Commodity/Technology										
	Forging	Casting	Powder Metallurgy	Extrusion & Rolling	Metal Removal	Joining	Surface Treatment	Forming	Other	Total
Aircraft	3.9	7.9	7.0	4.4	7.4	8.1	4.0	4.0	4.3	51.0
Missiles	–	–	–	–	0.7	1.0	–	–	–	1.7
Ships	0.9	1.6	–	–	–	7.6	1.6	–	1.5	13.2
Weapons	1.8	0.7	–	–	1.6	0.3	1.3	–	1.3	7.0
Ammunition	6.8	–	2.7	3.8	0.8	0.4	–	–	–	14.5
Land Vehicles	2.1	4.5	0.4	–	2.9	1.5	0.4	–	–	11.8
Support Equipment	–	–	–	–	–	0.8	–	–	–	0.8
Total	15.5	14.7	10.1	8.2	13.4	19.7	7.3	4.0	7.1	100.0

Table 4

Table 4 shows the distribution of funds among technologies for each commodity. The major commodities to which casting technology is being applied are aircraft, land vehicles, and ships.

Figure 2 summarizes the distribution of funds in the services' Five Year Plans. The pie represents a five year expenditure of $225 million. Thus, somewhat over $30 million is targeted for improvement of casting technology. With this amount of interest, the use of casting in manufacturing DOD systems should continue to increase, and casting technology should advance steadily. With industry participating in the program, the benefits should be felt across a wide range of products, many of which are outside the defense spectrum.

Acknowledgements

The subcommittee is indebted to the Ad-Hoc Committee that was responsible for the Casting Technology Workshop. The extensive efforts put forth by Messrs. Kennard (leader) and Clark of the Air Force Materials Laboratory, Mr. Gagne of the Army Materials and Mechanics Research Center, and Mr. Crisci of the David Taylor Naval Ship Research and Development Center are responsible for executing a very informative and productive meeting. The subcommittee is also indebted to the speakers, panel session chairmen, and the attendees whose comments and suggestions made the workshop worthwhile.

Precision Casting Quicker, Cheaper

Rock Island Foundry

What do false teeth, costume jewelry, and golf clubs have in common with the M85 machine gun?—All have precision cast parts, parts that are cheaper and can be produced faster than more conventional machined parts.

Rock Island Arsenal has had its own precision casting department for five years. This shop adds a valuable capability to Army production by turning out a wide range of parts for everything from the sporting rifle to the M198 howitzer.

And precision casting isn't the only unusual aspect of the Arsenal foundry. Whereas most foundries specialize in casting just one metal, Rock Island produces castings of steel, iron, aluminum, and bronze—all in the same shop. As the only government owned foundry in the Army, casting orders are filled from other arsenals and sometimes from outside vendors with Army contracts. Most of the castings, however, are sent to other sections of the RIA Operations Directorate for machining and assembly.

Technique Shines With Small Parts

The precision casting capability is particularly useful with materials that are too hard to machine easily or for very intricate parts. In either case, with normal castings machining is a long, costly process, whereby precision casting is relatively fast, easy, and inexpensive.

R. BRUCE WINE, a member of the staff of the Rock Island Arsenal newspaper, **The Target**, was selected as a DARCOM intern in September, 1977. A graduate of the Defense Information School's Information Officer School, Mr. Wine is active in all aspects of the newspaper including writing of news releases and responding to public queries. He has a Bachelor of Arts degree in Soviet Area Studies from the University of Missouri at Columbia. Following extensive graduate level work in Russian History, Mr. Wine entered the Federal Service in 1977.

Precision casting molds the part to exact size in a ceramic mold. In most cases, little or no machining is needed to finish the part. Casting precision depends on the ability of the die sinker who makes the permanent metal mold. If necessary, craftsmen in the Arsenal die shop can make molds to within a couple thousandths of an inch of the tool plans.

Precision casting can be used to make parts smaller than the front sight of a pistol or larger than the flash suppressor of the M85 machine gun. The size of the casting is restricted only by the strength of the ceramic mold. Large pieces, however, usually can be machined more easily and quickly from normal castings than fabricated by precision casting.

"Small parts that would be difficult to machine can be cast in as little as five minutes", says Lanny Ross, shop supervisor. "And because we can make as many as 16 pieces each cycle, our production potential is more than 1500 pieces a shift."

The permanent mold isn't damaged by the process and lasts indefinitely. Once the job is completed, the mold is saved for future use and all the instructions for making the part are permanently filed. If there's another order for the same part, finished parts can be made in just four days.

Process Simple, Quick

The procedure seems complicated, but once the permanent mold is made, production is simple. A permanent mold is machined in metal from tool drawings (Figure 1); this costs an average of $2000, although it can reach as high as $5000. The accuracy of the mold determines the precision of the part. This permanent mold is used to cast wax patterns, which are then attached to "trees" so that several parts may be cast at once. As many as 16 parts can be made on a single tree.

The trees are dipped into a fused silica (Figure 2) compound as many as eight times to build the ceramic mold.

An Unusual Shop

Figure 1

When the ceramic material has dried, it's put into an autoclave to melt the wax and empty the ceramic mold. After the mold has cured for an hour, it's ready for metal casting.

The molds are filled with molten metal, as seen in Figure 3. After the metal cools and hardens, the ceramic mold is broken off and the residue is removed by sandblasting or by a molten salt bath.

The last step is to cut the castings from the tree (Figure 4), grind off the risers and send the parts for any additional machining if needed. The tree is saved and remelted.

Many Advantages Evident

The in-house precision casting capability saves money in several ways. Generally, small production lots are more expensive, since most of the cost is in setting up production. And, because of other commitments, commercially produced parts often may be delayed. These problems are avoided by in-house production. There's another advantage to in-house production—the shop can reuse the scrap metal. With the price of some metals, that's a significant saving. "For instance," continues Ross, "stellite costs $23 a pound, and it comes from South Africa—a potentially unreliable source. But worn-out gun barrels are returned to the Arsenal to be melted and sold as scrap. We can take the stellite liners from those barrels, melt them, and use the metal to make new parts. That adds up to big savings."

Finally, RIA has found they have better control of quality. According to Ross, "Many purchased flash suppressors cracked when they were heat treated. None of ours has ever cracked."

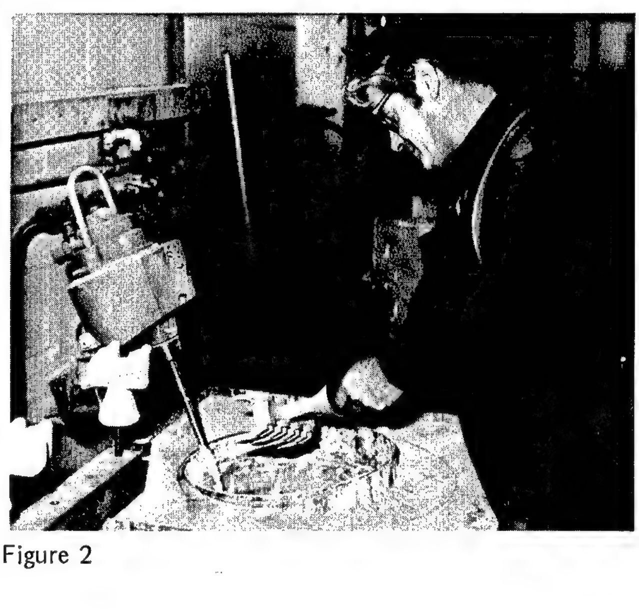


Figure 2

Figure 3

The precision casting department also contributes to research and development at the Arsenal. They can make experimental parts in machinable wax, make several ceramic molds, and cast several parts for less than it would cost to machine a single part from metal.

Meets Emergency Needs

The foundry's capabilities do not end with precision casting. Most of the castings currently poured in the foundry are weapons related—gun mounts and recoil mechanisms now are the principal products. But there are hundreds of other components cast in a wide variety of metals. Besides its production responsibilities, the foundry serves as a job shop and responds to many emergency situations. In many cases, it has shifted the major part of its production to the casting of a component needed on an emergency basis because of interrupted commercial supply.

Other New Techniques Developed

Precision casting is only one of several new manufacturing methods to be adopted by Rock Island Arsenal in recent years. Others include inertia welding, casting of armor steel, and direct numerical control machining.

"The Arsenal's ability to successfully perform its manufacturing mission depends upon maintaining a skilled work force and a flexible modern manufacturing capability," explains Ray Wildman, Director of the Arsenal Operations Directorate." We continually look for new processes and methods that will reduce costs, improve quality, or increase our ability to respond to changes in customer requirements."

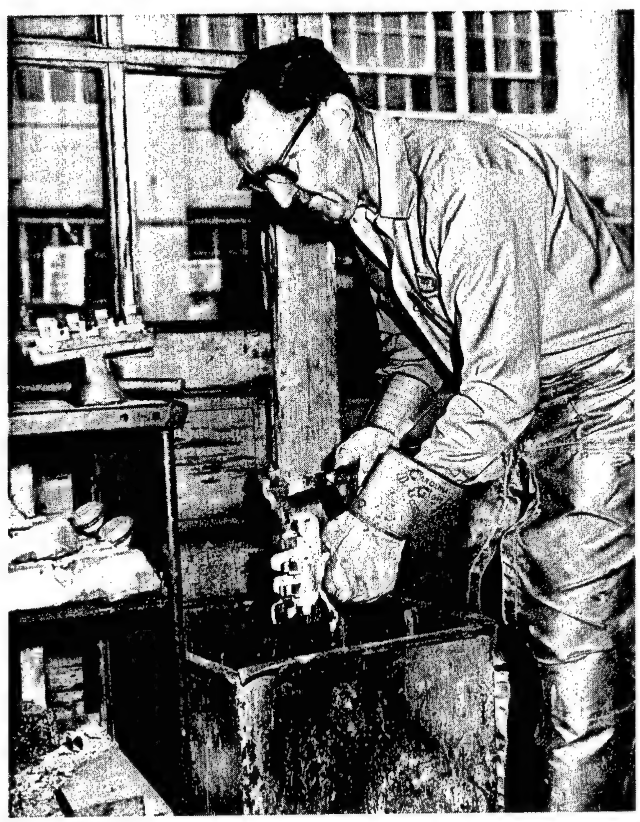


Figure 4

Potential Savings Near $ 5 Million

Army Looks To Titanium Compressor Casting

RICHARD MULLIKEN has been with AVRADCOM's Applied Technology Laboratory since 1974, at Fort Eustis, Va., where he has been involved in reducing production costs of small gas turbine components and in cost analyses of high volume production of these engines. He has had a long career in engine development. From 1937 to 1959 he was a project engineer with Fairchild Engine and Airplane Corporation, working on both piston and turbine engines. He moved from there to Thiokol Chemical, where he was responsible for technical definition of major rocket motor components and ground support equipment. In 1964, he joined NASA's Langley Research Center and was involved in research on high temperature materials and fiberglass and their application to rocket motors.

Full-scale production of cast titanium compressor casings for the T700 aircraft engine is nearing reality. A development effort under AVRADCOM MM&T funding monitored by the Applied Technology Laboratory has been successfully completed at General Electric and Precision Castparts Corporation. Cast casings are scheduled for use in all of the Army's third year buy of the engine, with savings estimated at $5 million over the previously forged and machined part (on the basis of 5,000 engines). Additional savings may be anticipated as other applications develop. A cast casing ready for final engine assembly is shown in Figure 1.

Current Process Complex, Wasteful

The casings, made from Ti-6Al-4V, are now fabricated by a complex forging, machining, and welding process—a process with high labor and material costs. The initial forging (Figure 2), with two casing halves joined end to end, weighs about 65 pounds. The halves of this casing are separated, the split flanges machined, and the parts rejoined. External features are welded on and inner and outer contours are fully machined to the final shape. The completed casing weighs about 8.8 pounds.

A design-to-cost analysis of the T700 made it clear that development of a practical casting process would result in significant savings. The study indicated that casting to near net shape would provide tremendous materials savings and eliminate much costly machining and welding. With a projected production quantity of 5000engines, these benefits would easily outweigh the necessary development investment.

Figure 1

As a result of this analysis, AVRADCOM undertook a casting process development effort with GE's Aircraft Engine Group and Precision Castparts as subcontractor in July, 1976. The program was aimed at casting the outer surface to size while integrally casting many of the external features.

Titanium Materials No Panacea

Such an undertaking was not without problems—many that were known from earlier experience with casting titanium. The use of titanium castings for aircraft engine structures is not common because of their cost and their producibility and quality limitations. However, moderate stress applications do exist at operating temperatures below 800 F, where titanium can be substituted for ferrous alloys producing a 40 percent weight saving.

Reactivity, High Melt Point Costly

The high cost of cast titanium structures is directly traceable to the metallurgical behavior of the alloy family. Those titanium alloys in current production have high melting points. Pouring temperatures exceed 3100 F, where titanium is extremely reactive with oxygen, hydrogen, and nitrogen, as well as with the ferrous alloys. Because of this reactivity, titanium must be melted and cast in vacuum consumable electrode (or "skull casting") furnaces.

These furnaces employ a water cooled copper crucible with a solid titanium lining, which prevents the liquid titanium from contacting any other material. Molds are made of special nonreactive materials. Thus, the melting and casting equipment and the mold materials are quite expensive.

Also, the consumable electrode equipment limits the amount of heat that can be applied to the molten bath. As a result, the titanium being cast is always just barely above its melting point and does not flow easily. To compensate, a large gating system is needed in order to fill the mold before solidification begins. A ratio of gating weight to casting weight of 10 or higher is not uncommon. This also introduces a major cost, since the gate material becomes contaminated and cannot be reused directly.

Thin Walls Hard to Produce

Producibility is the second major problem. In many instances, a part configuration that can be cast in nickel base superalloys, aluminum alloys, or stainless steels cannot be cast in titanium. Again, the low fluidity of the molten titanium is a key factor, making it difficult to cast thin wall sections. Furthermore, ceramic cores used to produce hollow castings and to provide small holes in castings are not available in compositions that are both easily removed from and nonreactive with titanium castings. If walls are thickened and hollow features eliminated to accommodate these limitations, the weight to be saved by using titanium castings may vanish.

Quality of finished castings is a third problem area.

Figure 2

Titanium castings are subject to the same types of defects as other types of castings. But the defects can be more difficult to overcome, again, because of the sluggish flow characteristics resulting from the low superheat and high reactivity of barely molten titanium. The most common defects are shrinkage (especially of the centerline variety in heavy sections), gas porosity, presence of nonmetallic inclusions, and surface discontinuities such as cold shuts.

Centrifugal Casting Provides A Solution

One casting technique that has been employed to better fill the molds is the use of centrifugal force in addition to gravity during casting. Centrifugal casting techniques used with standard investment casting shell molds go a long way toward overcoming the difficulties just described and insuring high quality titanium castings at reasonable cost. An additional benefit is that impurities, gas, and inclusions-being less dense than clean metal-gravitate in centrifugal casting to the inner surface where they can be removed by machining.

The process is particularly applicable to the T700 compression casing, which has large variations in section thickness. Filling this mold adequately in a static casting would require individual ingates and a central sprue which

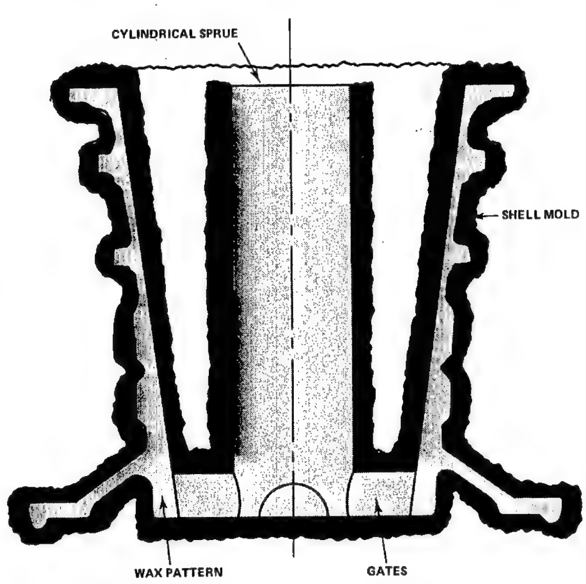


Figure 3

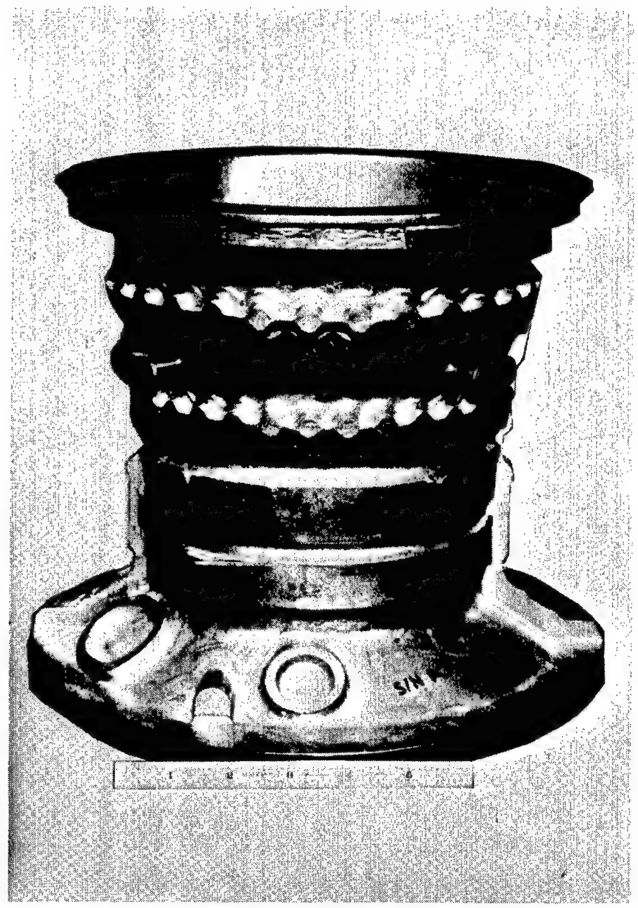


Figure 4

would be cast full. Although the pilot production mold (see Figure 3) includes a large diameter sprue and gates at the bottom (rear) end, the gates are very short and the sprue is largely voided by centrifugal action.

Figure 4 shows a casting produced using this mold. The casting is produced by melting a 35 pound ingot. After trimming and chemical milling, the casting weighs just 30 pounds, compared with the 65 pound forging weight. Finished, as in Figure 1, the casing weighs 8.8 pounds, the same as a forged part.

Figure 5 shows the improvement in material utilization by comparing forging, casting, and finished part sections.

Process Variables Interdependent

During process development, nineteen castings of the T700 compression casing were poured using temporary

epoxy pattern tooling. Initially, the aft section of the casing was cast solid, but radiographic inspection showed that shrinkage cavities formed. Changing the centrifuge velocity did not help, since the large mass present created a "hot spot" with resulting cavity shrinkage due solely to the geometry of the mold. The use of a steel ring insert attached to the pouring fixture bottom plate also proved unsuccessful.

The problem was finally overcome by pouring the entire aft section in a ceramic shell mold to yield a net shape casting. Using these patterns, five castings were produced in which the cavity shrinkage was completely eliminated. However, additional feeding ribs were required to produce sound borescope bosses and rear flanges. These ribs are removed during subsequent processing, and do not show in Figure 3.

Tooling for Pilot Production Developed

For pilot production, a wax injection die with eight segments was machined from aluminum. This die was designed to cast the basic outer casing contour, eight actuator pads, two borescope bosses, and three hollow bosses to which the air bleed ducts are welded. The actuator pads are formed by removable aluminum inserts or solid inserts and soluble wax cores. Using the pilot produc-

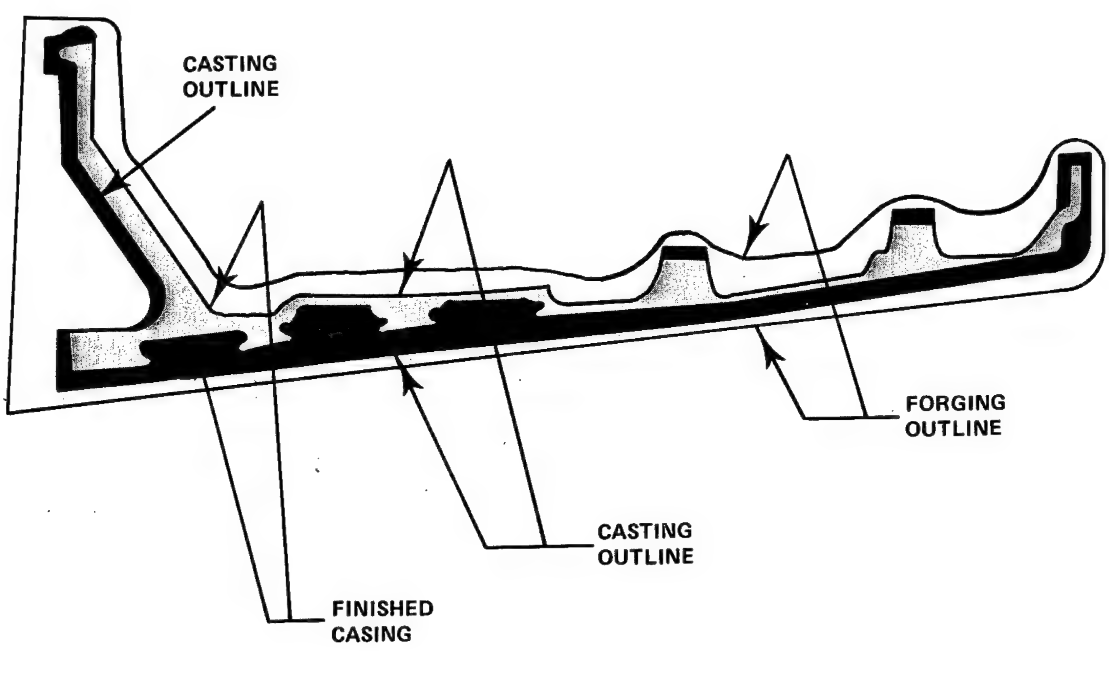


Figure 5

tion tooling, fifteen castings have been poured into molds preheated to 1800 F and rotating at 350 rpm.

Dimensional Stability, Distortion Related

Early castings were poured using a mold consisting of only the outer wall and back plate. The significant non-repetitive radial distortions that resulted were associated with the uncontrolled variation in wall thickness that this mold permitted. When the mold inner wall, sprue, and gates seen in Figure 3 were added, dimensional control was achieved. Subsequent adjustment to design of the sprue and gates was necessary to eliminate centerline shrinkage, which again recurred near the junction of the rear flange with the main body of the casing. As noted earlier, local ribs to adequately feed the rear flange were also found necessary.

This experience illustrates the interdependence of the process variables. Initial castings from soft tooling contained numerous shrinkage areas, but as the process was developed these defects were eliminated. Subsequent work with hard tooling concentrated successfully on stabilizing dimensions but reintroduced shrinkage as a side effect. The solution to the problem lies in providing better metal feeding to the thick sections of the casting by adjusting the size and number of feeding ribs. These castings are not hipped.

Casings Show Good Microstructure

To determine the quality of cast casings, specimen microstructures were examined. The examinations showed a typical annealed alpha-beta titanium structure with a matrix of transformed beta phase containing acicular alpha and alpha at the prior beta grain boundaries. Since 0.025 inch of material was chemically milled from all surfaces of the cast casings, no evidence of oxygen rich alpha phase (typically found on titanium castings in the as cast condition) was observed.

To determine mechanical properties, casings were annealed at 1300 F for two hours in vacuum and test bars were machined from various predetermined locations. Tensile, stress rupture, low cycle fatigue, high cycle fatigue, and crack growth rate tests were run. Data were taken at room temperature and temperatures up to 1000 F.

Design Safety Margins Adequate

Ultimate tensile strength and yield strength were approximately 10 percent lower than those for forged Ti-6Al-4V. Elongation was reduced by 8-12 percent and the area was reduced by 13-32 percent. Stress rupture properties of cast specimens correlated closely with those of average forgings, providing a high margin of safety for the cast parts. All other tests showed cast properties, although inferior to forged properties, to be comfortably above requirements of the casing with good margins of safety.

Walls of the three external ducts are 0.035 inch thick, and weight is critical. Efforts to cast the ducts integrally with the casing appeared promising initially and work to this end was conducted, meanwhile avoiding interference with the basic cast casing program. Wax duct patterns were formed separately and wax welded to casing patterns. Special gating for the duct flanges was added. Several variations were tried, but none was fully successful. Centerline shrinkage in duct flanges persisted, and it was necessary to cast duct walls 0.170 inch thick. Normal chemical milling would reduce this to 0.120 inches. Preferential chemical milling was tried unsuccessfully. Slight variations in thickness in the "as-cast" walls and variations in density in those areas caused problems. It was believed the problems encountered could eventually be solved, but with the added complexity of the casting and associated extra quality problems, the economics did not appear attractive. Efforts to integrate the ducts were therefore abandoned. Ducts will be attached by welding as previously.

Production Expected for Early Buy

With the centrifugal casting process proven, satisfactory qualification parts were delivered in early 1978. Castings have been scheduled to verify the stability of dimensions, and initial production is expected in time for the Army's third year buy of T700 engines. This refinement of centrifugal techniques for titanium alloy castings of complex shapes provides acceptable aerospace properties and represents a significant payoff for the Army's MM&T programs. Applied to the T700 engine program, savings of over $5 million are expected during the period of T700 production, with inestimable additional savings possible for future applications.

Castings Toughened A

Vacuum Furnaces The Key

ARTHUR AYVAZIAN has been employed as a Metallurgist at AMMRC and Watertown Arsenal since 1952. He holds a B.S. in Chemistry from Northeastern University and an M.S. in Metallurgy from Massachusetts Institute of Technology. As a Project Engineer, he has been responsible for a number of projects directed toward development of high strength steels, armor steels, and titanium alloys. He also has been active in the investigation of high temperature thermal treatments and their effects on cast and forged components. In 1976, Mr. Ayvazian was awarded the Army Research and Development Achievement Award for studies in the field of Electroslag Remelting of Steel (ESR). He is a member of the American Society of Metals.

Problems in reaching specified ductility and toughness levels in certain cast alloy steel components have long plagued Army production. Nonuniformity in properties is a part of the problem. When these properties are under required levels, critical in-service failures and decreased service life requiring costly and premature replacement procedures can result. Now, researchers at the Army Materials and Mechanics Research Center (AMMRC) have demonstrated that homogenizing heat treatments to reduce microsegregation will improve toughness and ductility and extend service life of these castings. Results of this Manufacturing Methods and Technology program provide a significant step toward developing a process to upgrade the quality of critical steel castings.

Particularly significant in AMMRC's research results is the fact that improvements in toughness were greater at higher strength levels. This was also true of ductility, although the improvements were not as dramatic.

Microsegregation a Major Problem

Microsegregation has been recognized as a major cause of irregularities in casting properties for some time. Research over the past 10-12 years has indicated that high temperature processing for long periods is an effective method of eliminating microsegregation in castings and improving their properties. However, vendors have been reluctant to utilize such drastic treatments since existing equipment was not really adequate and the costs of using it were quite high. The recent development of large, sophisticated vacuum furnaces has made such treatment much more practical.

Another deterrent has been that most previous studies used carefully designed test castings intended only for the research investigation. The applicability of such results to actual components could be questioned. AMMRC used full-scale steel castings of actual components. Thus, results are directly applicable to determining the feasibility of applying high temperature homogenization techniques as part of the production process.

High Strength Levels

CHEMICAL ANALYSES (IN WEIGHT PERCENT) OF HOMOGENIZED COMPONENTS									
Components	C	Mn	Si	Ni	Cr	Mo	P	S	V
Lunettes	0.39	1.13	0.62	0.15	0.26	0.12	0.007	0.018	0.06
155-mm Housing (A)	0.29	0.80	0.52	0.46	0.46	0.19	0.029	0.014	–
(B)	0.34	0.86	0.55	0.54	0.56	0.22	0.025	0.010	–
155-mm Muzzle Brake	0.30	0.95	0.33	2.00	0.99	0.45	0.016	0.017	–
152-mm Coupling (A)	0.29	0.73	0.35	2.76	0.85	0.55	0.014	0.010	–
152-mm Coupling (B)	0.31	0.75	0.31	2.75	0.87	0.52	0.010	0.009	–

Table 1

AMMRC Investigates Four Parts

Four separate castings were selected. These represented various shapes, dimensions, and alloy compositions. All were parts that had barely met required mechanical property specifications using prescribed heat treating procedures. The four parts, shown in Figure 1, were

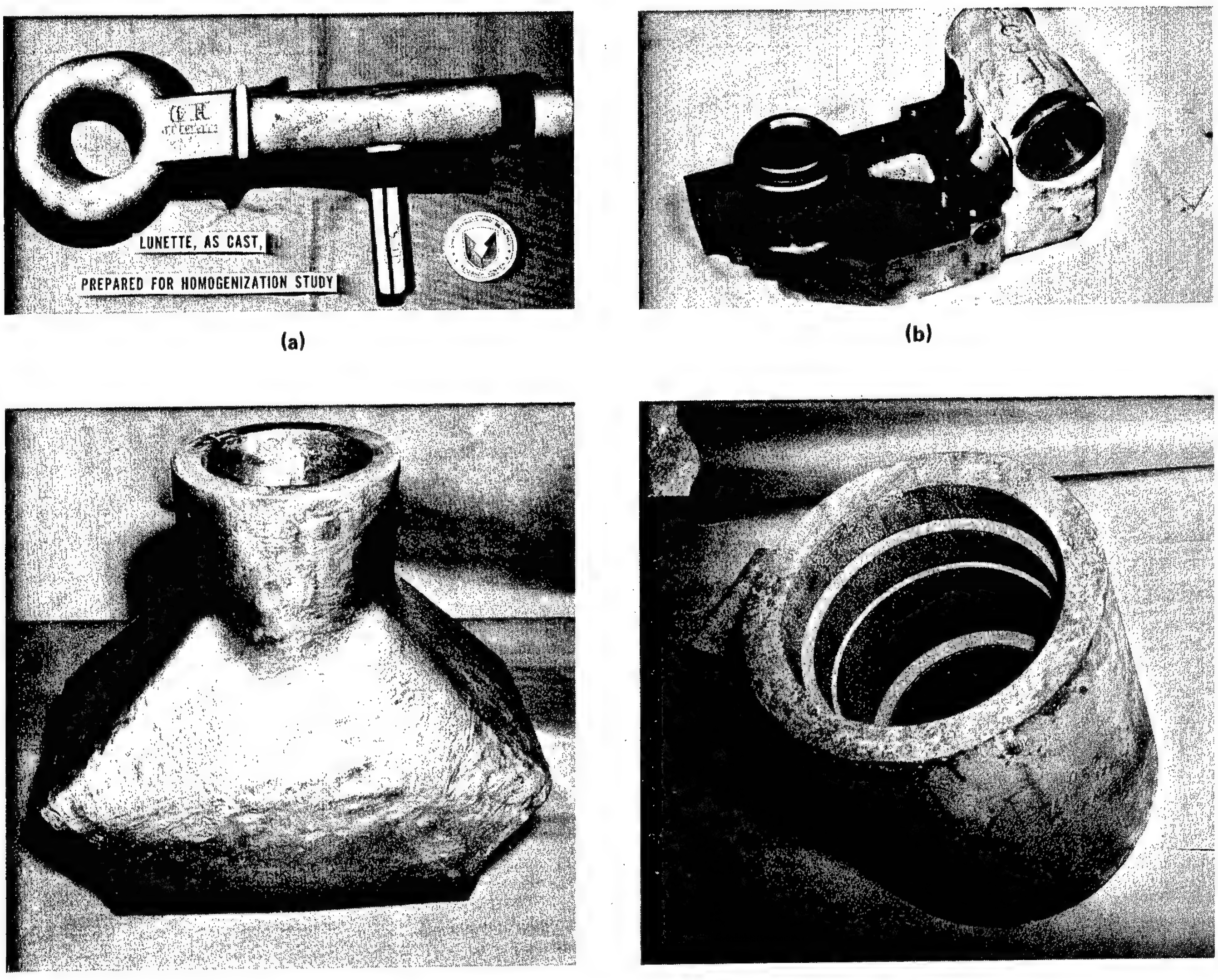
(a) Drawbar ring coupler (lunette)
(b) 155-mm M126 housing
(c) 155-mm XM199 muzzle brake
(d) 152-mm XM150E5 coupling.

Chemical analyses of the four low to medium alloy casting steels used for these parts are given in Table 1.

Homogenizing heat treatments were applied to samples of the four components, which were then tested and examined metallographically. Other samples were conventionally heat treated and comparison tests and examinations were run. A large, car bottom vacuum furnace was used to homogenize and normalize all castings except the lunettes. The treatments consisted of heating at 2400 F for 32 or 64 hours followed by normalizing at 1650 F. Effects of some modified heat treatments were also investigated. The lunettes were homogenized in a smaller vacuum furnace at 2300 and 2400 F, as shown in Table 2, followed by normalizing at 1650 F. All components, both homogenized and control, were austenitized and tempered according to vendor prescriptions.

Properties Improve

With all four components, ductility and toughness increased as a result of homogenization treatments. Mechanical property test results for housings, lunettes, and couplings are summarized in Figure 2. Toughness values were not only higher for the homogenized castings, but were even further improved at higher strength levels. Ductility showed a similar pattern, although the improvements were not quite as impressive. Results for muzzle brakes were similar, but in this case, such severe thermal treatment was not critical since the rather low specified properties were achieved with conventional treatments.



(a) (b)

(c) (d)

Figure 1

HOMOGENIZATION TREATMENTS		
	Treatment	
Lunette	Temperature, F	Time, hr
H 1	2300	32
H 2	2400	7-1/2
H 3	2400	15
H 4	2400	27

Table 2

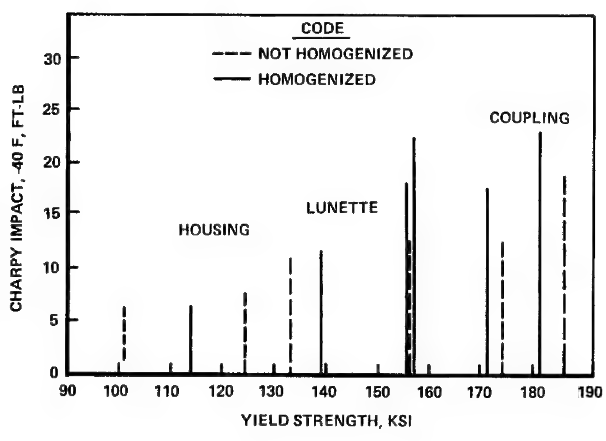
In the case of lunettes, which had a widely varying thickness, there was doubt that the specified properties for the 1-1/2 to 2-1/2 in. thick mass could be obtained under any condition. Properties of 1 in. thick sections met specifications.

One Exception to the Norm

In the case of the 155-mm housings (low alloy steel), homogenization alone had little effect on ductility and toughness. However, when the austenitizing and tempering treatments were altered, using a water rather than an oil quench, toughness improved dramatically.

With couplings, which were made from a better grade of steel, the homogenization treatment was responsible for increasing ductility and toughness to specified levels.

The results for all components indicated that homogenization can improve mechanical properties in these castings. However, the degree of improvement is related to steel composition, subsequent heat treatment, and structural condition of the castings prior to homogenization. The necessity for such treatment depends on the specified property level.



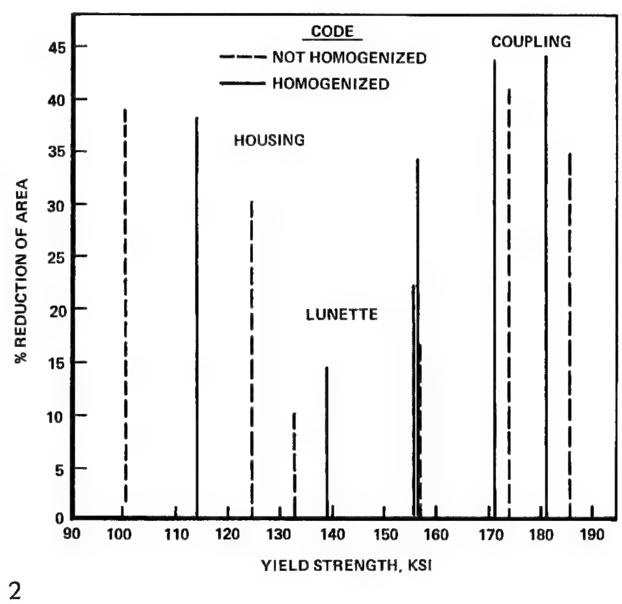


Figure 2

Directionally Solidified Blades: Greater Strength

Single Crystal Process Controls Structure

Presently in use on four Pratt and Whitney engines, superalloy turbine blades cast by the directional solidification process have a structure that offers distinct advantages over conventional equiaxed cast blades. These advanced blades have greater stress rupture strength, improved thermal fatigue resistance, and greater tensile strength. Although fabrication costs for the directionally solidified blades are still 1.5 to 2 times those of conventional blades, these costs have dropped sharply from their initial levels. Since the improved properties mean longer life and lower operating and maintenance costs, the blades are very attractive for use in high performance gas turbine engines.

Meanwhile, work continues on single crystal blades, a logical extension of the directional solidification process. Full development of the single crystal process could mean significant savings in mission, engine development, and turbine overhaul costs.

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New Process Answers A Need

Materials and their processing historically have played a key role in the development of gas turbine engines. As required performance levels of these engines increased, material property requirements for components became more and more demanding. Today, the need to conserve raw materials and energy calls for lower specific fuel consumption and increased performance, with no loss in maintainability and reliability. Engine designers have responded to these needs by developing complex cooling schemes for turbine components at the same time that materials engineers have developed new alloys and new methods for controlling alloy grain structure. Casting advances have resulted in a new generation of superalloy materials with a

controlled cast structure. The controlled structure is obtained by directional solidification. A logical extension of the process is the single crystal blade.

First, consider the directionally solidified blade, which is already in use. Directionally solidified superalloys provide three important advantages over the randomly oriented microstructures of conventional castings:

- **Enhanced stress rupture strength** through virtual elimination of strength limiting grain boundaries perpendicular to the direction of solidification, the major stress axis.
- **Increased resistance to thermal fatigue** thanks to a substantial reduction in elastic modulus in the solidification direction, which in turn reduces stresses generated by thermal gradients.
- **Greater strength** because a large ductility increase in the growth direction allows substantially greater amounts of alloying elements to be added without affecting ductility.

Single Crystal Cost Reduced

Initially, the cost of directionally solidified blades was high because development cost, capitalization, and determination of realistic quality standards were added to the hardware cost. With these problems overcome, the blades now cost only 1.5 to 2 times as much as conventionally cast blades.

Directionally solidified blades now are used in several Pratt and Whitney engines. Working with their major vendors (Howmet, TRW, and SMP), Pratt and Whitney has developed the withdrawal technique of directional solidification to a point where up to 90 percent yield is obtained on complex turbine blades and vanes. These components now are used in four Pratt and Whitney engines—the JT9D for the Boeing 747, the F100 for the F-15 and F-16, the TF30 for the F-111, and the PT6. These engines have accumulated more than 1.5 million hours of field use, and over 300,000 airfoil castings have been made by Pratt and Whitney vendors.

Three Basic Processes Available

There are three basic directional solidification processes —(1) withdrawal, (2) RAM-DS (Rapid Automated Multistation—Directional Solidification), and (3) exothermic. **Withdrawal** is a process developed by Pratt and Whitney, TRW, and Martin Metals. In this process, a hot ceramic shell cluster mold is placed on a chill plate atop a precision, speed controlled elevator mechanism. As solidification starts to progress up through the mold because of heat conduction to the chill plate, the mold is withdrawn from the hot zone at a predetermined rate past a radiation baffle at the base of the susceptor. As heat is removed by radiation from the solid portion of the casting as well as by conduction through the chill plate, an effective thermal gradient is maintained at the solidifying interface. As a result, a controlled microstructure is obtained. Figure 1 illustrates conventional stationary casting and the withdrawal process. Also shown are the RAM-DS process and exothermic casting, discussed in the following paragraphs.

Integrated Assembly

In General Electric's **RAM-DS** process, a single blade self-pouring mold is used. This process differs from withdrawal casting in that all gating, down runners, and pouring spews are part of a single wax assembly. A fusible metallic plug in the area between the melt cup and blade mold is made from material with a higher melting point than the casting alloy. This plug allows the alloy charge to become completely molten before it enters the mold. When proper plug material and furnace parameters are selected, the charge superheat—and thus the casting microstructure—is accurately controlled.

Low Mold Temperature Gradient

The third process, **exothermic,** was developed by the Detroit Diesel Allison Division of General Motors for the Air Force and is suitable for second source, directionally solidified materials for military applications. The basic process utilizes an exothermic material to supply the extremely high mold preheat temperatures required for directional solidification. This technique is different in that the mold is externally preheated by the uniform temperature exothermic pack so that there is no appreciable temperature gradient in the mold before pouring.

After pouring, the rapid extraction of heat by the chill plate produces the temperature gradient in the melt necessary for directional solidification. Without auxiliary heating apparatus or moving heat sources (such as induction coils) to extend the range of controlled temperature gradients, the exothermic process is limited to configurations no larger than 5 to 6 inch dimensions. However, it offers cost savings for a broad range of smaller airfoils. The process is shown schematically in Figure 2.

Briquettes Used As Heat Source

The mold is contained within a preformed insulating sleeve and surrounded by the exothermic material to form a pack, as shown in Figure 3. Next, the exothermic material

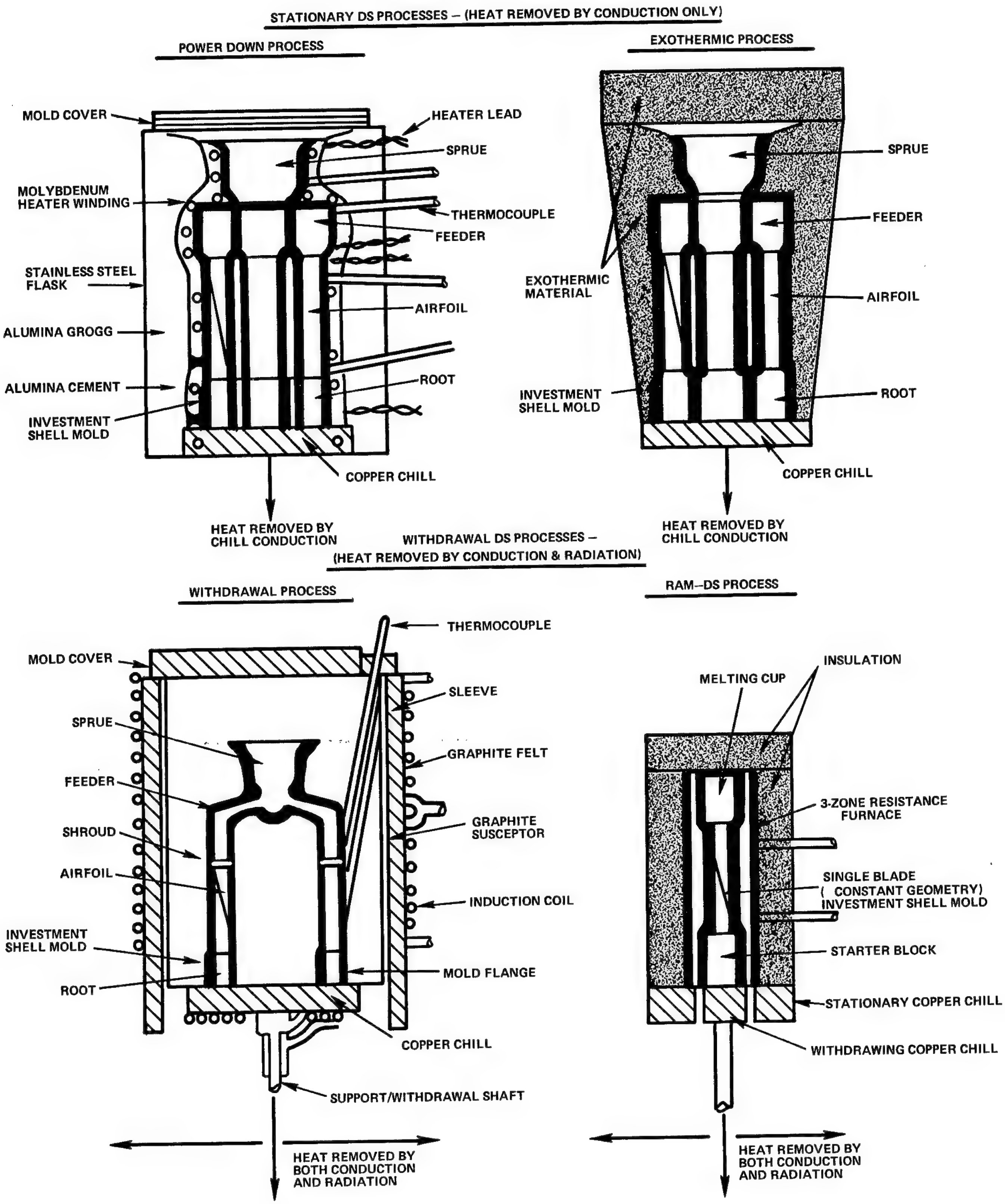
STATIONARY DS PROCESSES – (HEAT REMOVED BY CONDUCTION ONLY)
POWER DOWN PROCESS
MOLD COVER
HEATER LEAD
SPRUE
MOLYBDENUM HEATER WINDING
THERMOCOUPLE
FEEDER
STAINLESS STEEL FLASK
AIRFOIL
ALUMINA GROGG
ALUMINA CEMENT
ROOT
INVESTMENT SHELL MOLD
COPPER CHILL
HEAT REMOVED BY CHILL CONDUCTION
EXOTHERMIC PROCESS
SPRUE
FEEDER
EXOTHERMIC MATERIAL
AIRFOIL
INVESTMENT SHELL MOLD
ROOT
COPPER CHILL
HEAT REMOVED BY CHILL CONDUCTION
WITHDRAWAL DS PROCESSES – (HEAT REMOVED BY CONDUCTION & RADIATION)
WITHDRAWAL PROCESS
THERMOCOUPLE
MOLD COVER
SLEEVE
SPRUE
GRAPHITE FELT
FEEDER
GRAPHITE SUSCEPTOR
SHROUD
AIRFOIL
INDUCTION COIL
INVESTMENT SHELL MOLD
MOLD FLANGE
ROOT
COPPER CHILL
SUPPORT/WITHDRAWAL SHAFT
HEAT REMOVED BY BOTH CONDUCTION AND RADIATION
RAM–DS PROCESS
INSULATION
MELTING CUP
3-ZONE RESISTANCE FURNACE
SINGLE BLADE (CONSTANT GEOMETRY) INVESTMENT SHELL MOLD
STARTER BLOCK
STATIONARY COPPER CHILL
WITHDRAWING COPPER CHILL
HEAT REMOVED BY BOTH CONDUCTION AND RADIATION

Figure 1

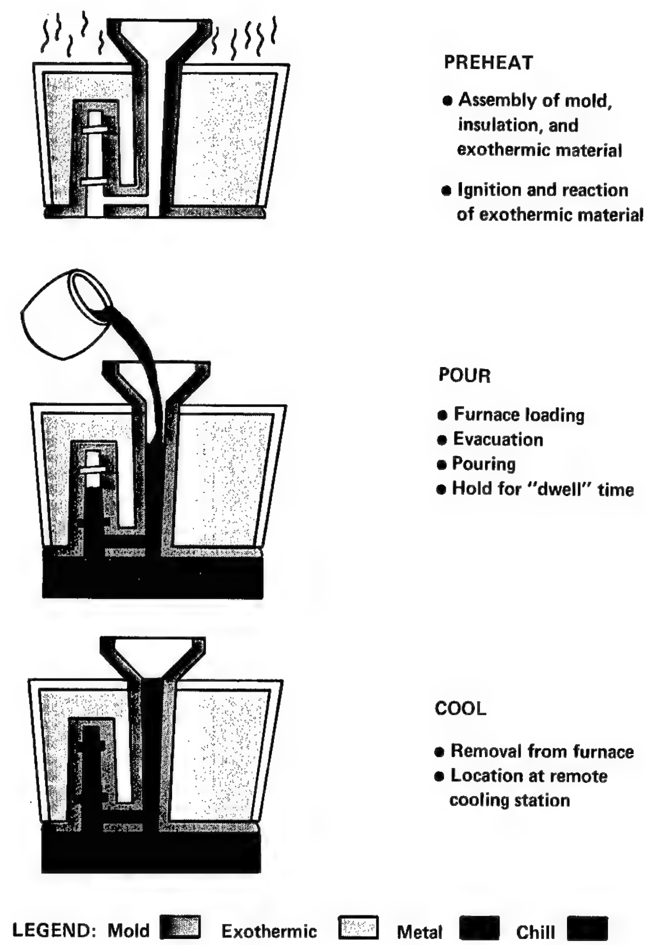

Figure 2

is ignited and allowed to burn on the foundry floor until the reaction is completed.

After the mold and surrounding pack have reached the desired preheat temperature, they are moved as a unit and placed on a copper chill plate inside a conventional vacuum furnace for pouring. The furnace chamber is evacuated and the mold filled conventionally. After pouring, the chill plate rapidly transfers heat from the bottom of the castings, providing for directional solidification of the castings. Finally, the mold, still surrounded by its heat source, is removed from the furnace and transferred to a secondary cooling station in a convenient holding area.

Installation Simplicity A Feature

The process requires no specialized furnace equipment—only installation of a chill plate—so its introduction in plants with conventional melting and pouring equipment does not entail the high costs of introducing other commercial directional solidification methods. The process could be automated easily to further reduce costs to levels only slightly higher than those of conventionally cast airfoils.

Figure 3

The exothermic process was used on airfoil components for several engines including the F103 (General Electric), TF-41 (DDA), and T-55 (Avco). Figure 4 shows the wax cluster used for T-55 blades. AiResearch Manufacturing Company currently is using the exothermic process at Jetshapes, Inc., to make blades for its commercial TFE731-3 engine under NASA contract.

Dual Property Wheel Promising

In a further Detroit Diesel Allison development as part of a joint Air Force/Army program, DDA is casting a direc-

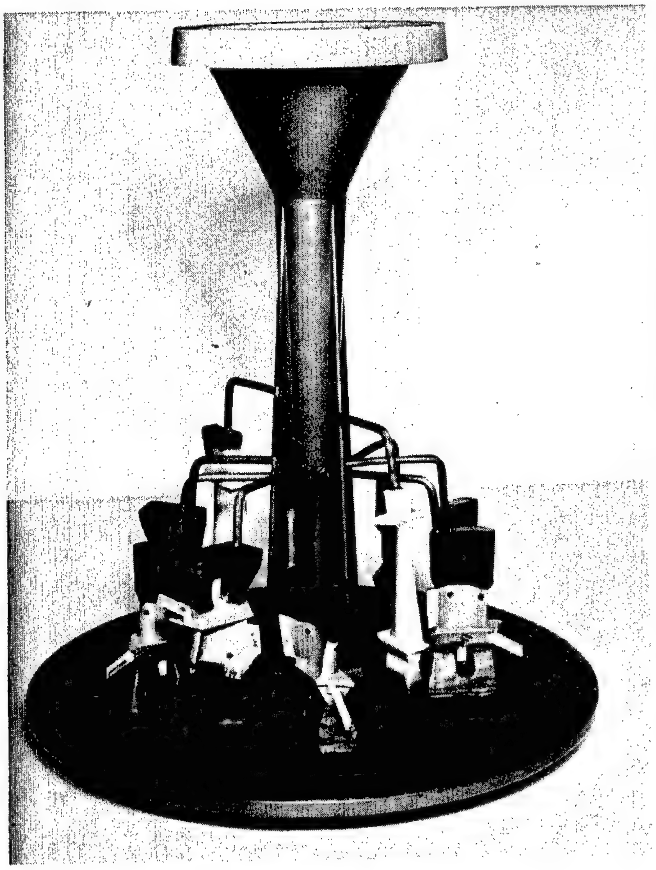

Figure 4

tionally solidified ring (Figure 5), which is machined and bonded to a powder hub (Figure 6), thus providing a dual property wheel. The T63-A720 engine using this wheel is being introduced to the Army's LOH helicopter fleet on a retrofit basis. Dependent upon budgetary considerations within the Army, as many as 2200 of these engines may be needed over 4 or 5 years. With this volume of engines, doubling component life through the dual property approach could lead to significant cost savings. As further applications are identified, even greater savings will accrue.

Further Advantages of Single Crystals

Single crystal castings are a logical extension of the directional solidification process and offer advantages over both equiaxed and directionally solidified castings. Using single crystal castings, engine performance can be upgraded because of property improvements that allow increased

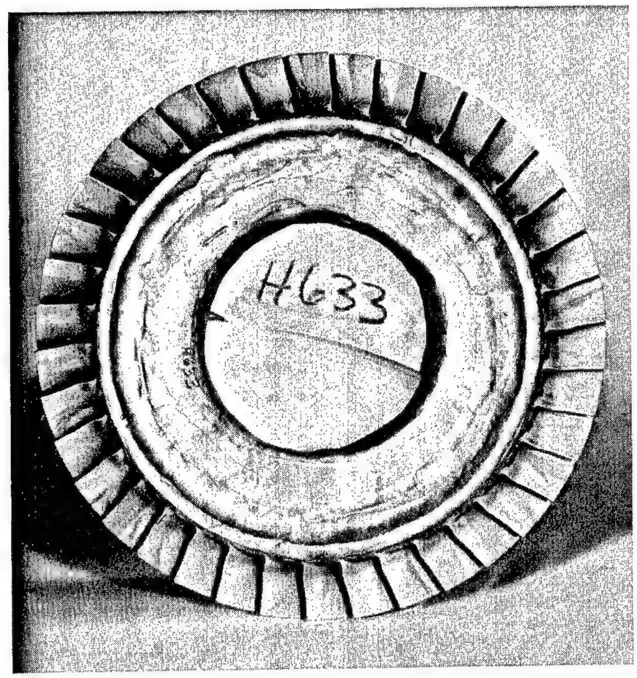

Figure 5

inlet temperatures without resorting to blade cooling. The blades will last longer because they have no grain boundaries. Because there are no grain boundaries, the composition can be changed to improve strength, ductility, and oxidation resistance. The resultant single crystal alloy has a higher melting point and can be heat treated to achieve increased strength at operating temperature.

Single crystal castings are produced with the same methods used for directionally solidified castings. Exothermic, withdrawal, and RAM-DS techniques all have been

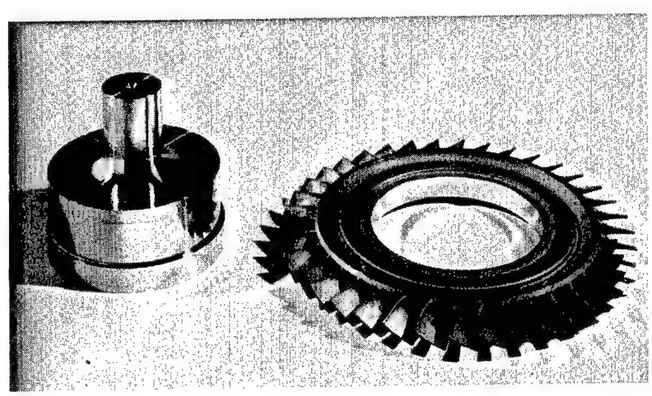

Figure 6

used successfully. The unique difference common to all three is that the starter block provides a way to sort out a single grain from all of those that nucleate at the chill surface. Starters in use today usually force the growing grains to follow a circuitous route from the chill plate to the casting cavity. This route may be in the form of a helix, or it may contain one or more right angle bends. Only the one grain that is oriented to follow this route will survive the growth process. This single grain then grows into the casting cavity.

Crystal Structure Affects Design

The crystallographic orientation of the single crystal castings is important. Nickel base superalloys are anisotropic and the designer must consider the orientation of the crystal in his blade design. This anistropy now can be used by the designer to utilize the best combination of properties; however, if selective properties are required, specific orientation can be obtained by the use of seed crystals.

In the joint Air Force/Army program mentioned earlier, single crystal turbine blades are being made at TRW. Figures 7 and 8 show equiaxed and single crystal dual blades, respectively. The single crystal blades allow a 125 F

Figure 7

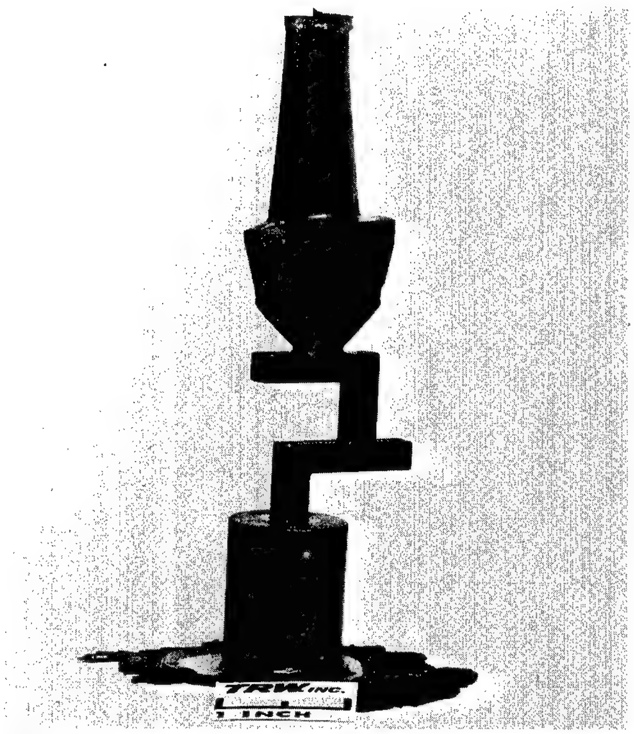

Figure 8

operating temperature increase over that of the current equiaxed blades. This improved operating capability can be used to

- Increase the mission capability of the current VSTT through increased thrust. The 125 F operating temperature increase corresponds to a 9 percent thrust increase. Therefore, the aircraft gross weight allowance will increase and this can be used for added fuel. The extra fuel will increase available mission time 21 percent, thus the cost per mission will go down by 21 percent.
- Make the engine useful for a future mission by eliminating the need for special engine development. This would represent a $6 to 7 million savings.
- Retain current temperature and thrust levels and thus increase the overhaul life of the turbine section six to seven times without throwing away the rotor, as is sometimes done at present.

It is obvious that the single crystal materials will provide improvements over directionally solidified materials, but manufacturing technology development still is required to realize these advances. In the meantime, directionally solidified airfoil components are available with significant advantages over conventional castings.

Team Approach Pays In Long Run

Cast Parts For R&D Systems

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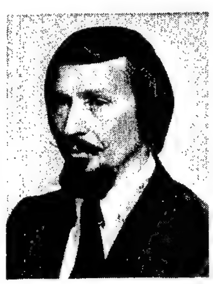

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Ten years ago, investment casting of large, low alloy steel parts was considered unfeasible if not impossible. Today, such parts are turned out "almost as easily as popcorn". Development of that capability is due in no small way to a radical departure from the norm in R&D work at General Electric's Armament Systems Department in Burlington, Vermont. In its approach, G.E. designs and procures cast parts during the R&D phase. The company emphasizes an early start, use of a casting "team", and close cooperation with the foundry.

GAU-8/A Development Boosts Investment Casting

As an example, consider investment casting development. Initial design of the GAU-8/A 30-mm gun for the A-10 aircraft nearly 10 years ago called for investment casting of low alloy 4340 steel. G.E. was told by several leading foundries that this could not be done. The size, the alloy, and the configuration simply ruled against it.

But G.E. did not buy that. The company put together a team of casting specialists who convinced themselves it could be done. Using their own "book" on foundry capabilities (developed in-house), they selected a foundry they thought could do the job. Then they convinced the foundry it could be done and worked closely with them to see that it was done. And—most important—they started developing the casting capability at the beginning of the R&D process.

The combination of G.E. expertise in metallurgy and the foundry's expertise in casting resulted in decent castings right from the start. By the time the gun had gone through the R&D and preproduction stages, any remaining metallurgical and pouring problems were solved. The casting capability was fully developed and the foundry was ready for production—production of a part that "couldn't be cast". Now, large low alloy steel castings have become commonplace.

As a sidelight to the casting development, the GAU-8/A was unusual—even unique—in another respect. It represents the only case in which a gun was designed first and an aircraft built around it. The G.E. approach to casting development contributed to making this unique development possible. But what's different about this approach?

Casting Development Part of Design Effort

The usual approach to developing parts that will be cast during final production is to take solid stock and hog out the parts for R&D models. The reasoning is that it is too costly and time consuming to try and cast these parts simply for the development effort. On the other hand, hogged out parts don't provide a true picture in testing and they don't do a thing for casting development.

That is how G.E. felt, at any rate. As a result, a team approach was instituted in which casting capabilities are

developed right along with the design during the R&D phase. This approach has been applied in nearly all of G.E.'s newest weapon developments, including the GAU-8/A. G.E. feels that developing castings for the initial R&D design offers several important advantages:

- R&D testing is more credible using a component of the same weight and mechanical properties as the items planned for production.
- The foundry is more nearly ready for preproduction and production units because of capabilities developed during the R&D phase. Also, the tooling developed during R&D work can often be used for production.
- The possibility of getting quality cast parts when production rolls around—and this is often a real problem—is assured.
- Development costs are lowered in the long run.

Effort Spurred By Casting Developments

Several developments in the casting industry have helped make it feasible and economical to design and procure castings for R&D work, as G.E. is doing.

- The investment casting industry has seen tremendous growth in both the size (castings exceeding 2000 pounds have been successfully poured) and complexity of castings.
- The strength and castability of modern low cost casting materials gives the design engineer an entirely new set of resources to work with.
- The cost and production time for complex, high quality investment castings are competitive with those for hogouts, thanks to the development of new, efficient investment processes.
- The advancement of in-process welding has given foundries greater flexibility and fostered a willingness to innovate.
- The rapid growth of investment casting techniques has promoted a close working relationship between the foundry and the design engineer—a relationship that ensures full realization of the advantages of these techniques.

Figures 1 through 4 show typical castings that G.E. has used in initial R&D units. The gun saddle in Figure 1 is used in the Army's M163 and M167 Air Defense Systems developed for ARRCOM. Only minor changes were made in the casting patterns for production units. The same is true of the helicopter turret gimbal (Figure 2) for the Army's universal turret, which is used in the M197 gun. This also was built for ARRCOM. Figures 3 and 4 are steel investment castings for a new 25-mm gun currently under development—a gun rotor and gun housing, respectively. Each of these parts could have been hogged out of solid stock. But the cost would have exceeded that for the combination of casting and machining.

All of this presents a convincing argument, but still leaves the question of lead time. Won't R&D be slowed waiting for castings? What does G.E. do to secure R&D castings in a timely manner? This is where the key elements in G.E.'s approach—an early start, a casting team, and working closely with the foundry—come in.

Casting Team Vital

G.E. feels the key to success in the design and timely procurement of R&D castings is involvement. So at the start of development, G.E. organizes a team of specialists in a casting field who are knowledgeable in the areas of casting design, foundry processes, and manufacturing techniques.

Every available source of expertise is used from the start of the design phase right on through production. This is accomplished by making up the casting team from a manufacturing engineer, a metallurgist, a quality control engineer, and a buyer.

After the initial design layout of the casting is made, but **before** the drawing is finalized, the casting team conducts a producibility review. In this review, the manufacturing engineer considers dimensional features and tolerances of the part, along with proper placement of

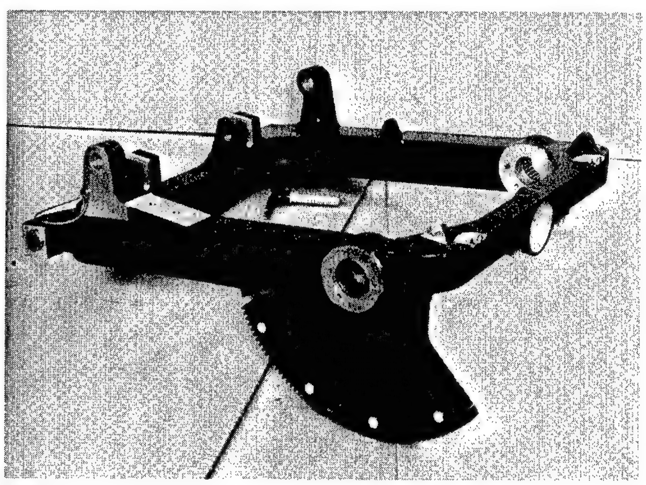


Figure 1

machining datums and tooling points. These factors must be interactive and compatible with the particular type of casting to be produced. For instance, the tolerances of features that are to be cast and not further modified by machining must be compatible with the casting process.

Hard Questions Posed

The manufacturing engineer may also lay out a preplanning flowchart to determine the types of machining needed, identify required tooling, and estimate costs of tooling and machining processes. He may question the use of close tolerances that inflate tooling or machining costs. He may also question the type of casting. For instance, a sand casting is generally less costly to produce than an investment casting, but generally requires more machining. The part may be preplanned as both a sand and an investment casting, or possibly some other type of casting.

The cost of casting and the subsequent costs of tooling and machining for all the casting processes under consideration are estimated and compared. In addition, the available technology to produce the particular casting in the required time is considered. The manufacturing engineer reviews and resolves any problems or suggestions with the design engineer.

Metallurgy, Quality Judged

After the manufacturing engineer's review, the metallurgist and quality control engineer review the findings and recommendations with an eye to metallurgical soundness and dimensional control. They consider material requirements, heat treatment, nondestructive testing requirements, and any particular gauging, inspection tooling or check fixtures that may be required. Potential difficulties because of the type of alloy, the casting process, dimensional control, or the specified grade of casting are noted. Changes in tooling points, datums, material, etc., that are necessary to produce a metallurgically sound casting with the necessary dimensional control are resolved with the help of the design engineer and the manufacturing engineer.

When the producibility review is completed, an engineering drawing is issued. This drawing is again reviewed by the casting team to ensure completeness and accuracy. At this point, someone is needed to cast the R&D part. Selection of a foundry is a very important aspect of G.E.'s approach.

Foundry Capabilities Well Known

As indicated, G.E. maintains a "book" on foundries—a listing of qualified foundries showing the types of casting processes, size capability, alloys poured, and a complexity rating. It's even better than the yellow pages. All qualified foundries have had a previous onsite review by the casting team to determine their capability to produce the various types of castings. G.E. knows quickly what foundries have the capabilities they need for a particular casting.

To help with selection, the casting in question is given a complexity rating. Foundries in the "book" that are capable of producing the casting—based on a "looks like" approach and past performance—are then listed. In some cases, there may be only one or two foundries that appear capable of producing the desired casting within the required time and budget.

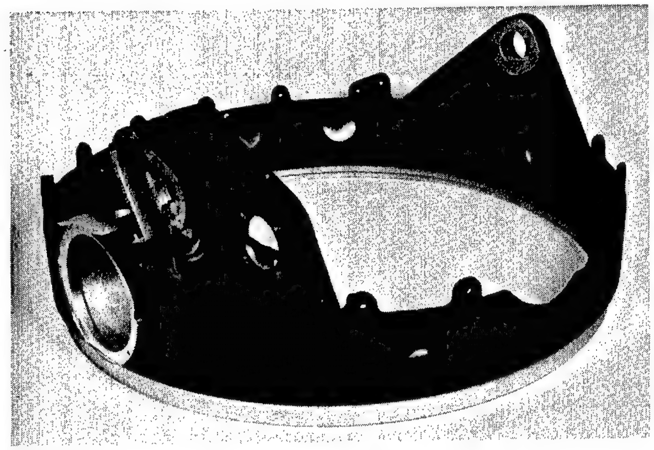


Figure 2

The buyer solicits quotations from the foundry or foundries chosen by the casting team. He may also set up preaward meetings between the casting team and foundry personnel to resolve any questions. He then places an order based on the quotations received and the inputs of the other members of the casting team.

At this time, the casting team may choose a foundry that would be unsuitable for a production contract but whose profile indicates that it can produce an R&D item quickly and at minimum cost. The idea is to work closely with the foundry to challenge its personnel—to develop the firm's capability. G.E.'s feeling is that when R&D and preproduction are complete, the foundry will have a production capability. Furthermore, for the particular part, this capability will be unmatched elsewhere. This is a very positive approach—some might consider it risky. G.E. has found that it works!

Flexible Design Aids Casting Development

Another key element in the G.E. approach is that the design is not finalized when work with the foundry begins. G.E. remains flexible, seeking foundry suggestions. By soliciting and adopting design change suggestions offered by the foundry, the best overall design can be obtained. Foundry involvement in the design process is considered vital to success. It develops solid foundry support of the program, while assuring the foundry of G.E. involvement and support should unforeseen problems occur. The foundry realizes it can provide design input and that it has ready access to the design engineer. This encourages innovation—the foundry is much more likely to seek ad-

vances in the state of the art than if it were given a "frozen" design.

Team Members Play Key Role

During casting development at the foundry, the casting team plays an important role in ensuring that the end product meets or exceeds all design requirements. Each member of the casting team is utilized to provide the foundry with all the information it needs to guarantee success at minimum cost and within the allotted time.

For example, the manufacturing engineer and quality control engineer work closely with the patternmakers to ensure dimensional control. Patterns and investment casting waxes are visually and, at times, dimensionally inspected by the engineer and members of the casting team.

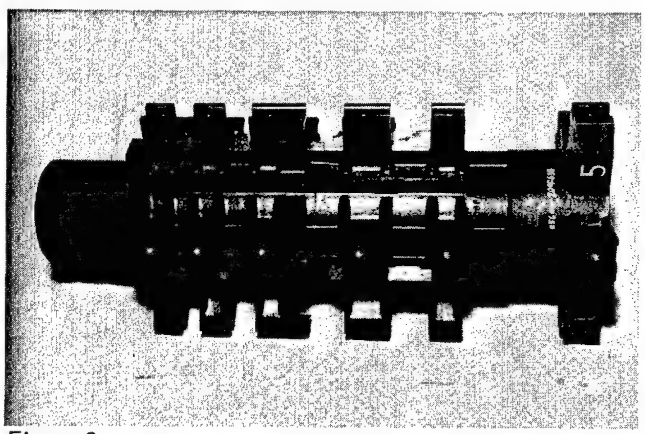


Figure 3

The metallurgist works with the foundry engineer in developing any special metallurgical requirements. If necessary, nondestructive testing specialists are consulted to ensure proper test and inspection.

At the same time, the casting team maintains close contact with the design engineer. By providing this sort of liaison, G.E. can respond quickly to any problem that may arise and ensure prompt resolution. The casting team concept improves the probability of success, while reducing time and costs.

Imperfect Products Salvaged

G.E. realizes that the first castings produced may have metallurgical or dimensional shortcomings. When this happens, techniques such as inprocess welding are applied to correct discrepancies, avoiding the expense of recasting the part. In this manner, a casting for engineering development can be obtained quickly at a reasonable cost. Should the first engineering casting be simply unusable, changes can be readily made to the die or pattern and another part produced in much less time and at less cost than would be possible with a fully machined part.

A Solid Approach

G.E. is sold on its approach. Designing and procuring castings right at the start of an R&D project eliminates much redesign effort during preproduction. The unknowns encountered in changing from hogouts or forgings to castings are eliminated. Most problems in design are solved before going into production or even preproduction.

Furthermore, the dollars spent in developing machining and inspection tooling are not lost at the end of the R&D phase as with hogouts. And the overall learning process is accelerated. The foundry gains the knowledge it needs to provide a production part; G.E. gains the knowledge it needs to set up production processes and inspection. In addition, the close contact between G.E. and the foundry provides information needed to successfully initiate timely procurement of production quantities of the cast components.

The R&D casting concepts employed by G.E. can help anyone designing cast parts. Use of these concepts provides a smooth transition from R&D to preproduction to production. The customer can feel assured of a superior product at reasonable cost with on-time deliveries. Furthermore, the foundry has enhanced its competitive position with improved capabilities and the state of the art in casting technology is advanced another notch.

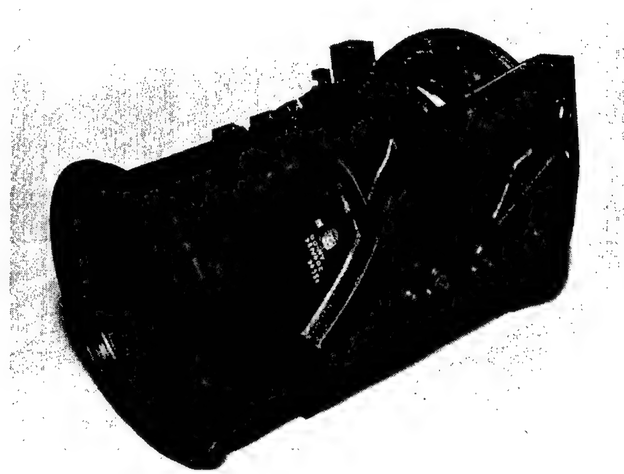


Figure 4

SAMUEL STORCHHEIM received B.S. and M.S. degrees in Metallurgical Engineering from the Polytechnic Institute of Brooklyn. He has over 20 years of experience in powder metallurgy including the pioneering of direct rolling of heated metallic particles into finished strip, aluminum powder metallurgy using protective sintering atmospheres, and aluminum powder metallurgy sintering in air. He currently is working at IIT Research Institute developing the use of squeeze casting technology and the new hot pressing method. Mr. Storchheim has over 30 patents and 70 publications.

Squeeze Cast Missile Domes Feasible

60 Pound Part Less Costly

Successful squeeze casting of PATRIOT missile domes at the Illinois Institute of Technology Research Institute (IITRI) has demonstrated the capability of this process to fabricate relatively large parts, thereby reducing production costs. With a few modifications to the laboratory process, short run production of missile components or other larger forgings (a few thousand parts per year) appears feasible. Use of this unique process would increase productivity, reduce costly machining time, and cut scrap losses.

In squeeze casting, molten metal is poured into a die. Pressure applied by a top punch then "forges" the metal to near the final net shape as it solidifies. Production costs for squeeze casting are much lower than for conventional casting or machining of forgings. This is because the process requires less metal and much less machining time thanks to the near net shapes possible. Metallurgical properties are also improved over those of conventional castings. Squeeze castings have near wrought properties such as those available in forgings. A nonporous metallurgical structure and fine grain account for the improved properties.

Process Adopted From Soviets

IITRI researchers have been working with squeeze casting since "discovering" the process in Soviet literature about 10 years ago. During that time, they have investigated casting of both ferrous and nonferrous metals. Their work has resulted in a number of proprietary applications that are now being used in production by

various sponsors. However, the largest squeeze casting made in that period weighed only about 20 pounds. Thus, adaptation of the process to the 60 pound forward dome of the PATRIOT missile presented some new problems.

IITRI's first look at larger parts came when the Army Missile Research and Development Command (MIRADCOM) asked them to investigate squeeze casting for the other large steel forgings for missile components. The potential of squeeze casting to sharply reduce these costs appeared worth a closer look.

Application to Missile Dome

The PATRIOT forward dome is made of D6AC steel. Its shape and dimensions are shown in Figure 1. Top and bottom views of a finished part are seen in Figure 2. Figure 3 illustrates the squeeze casting process used by IITRI to fabricate the dome.

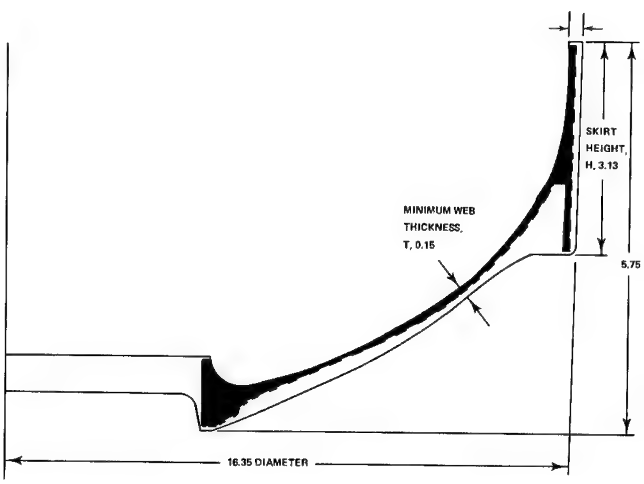
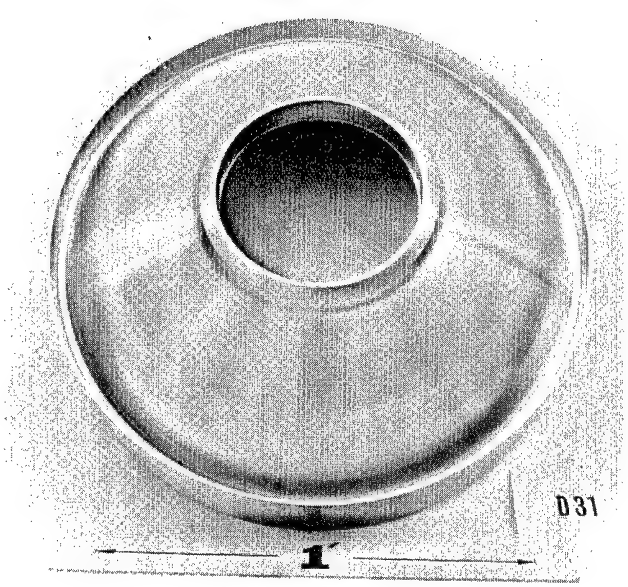
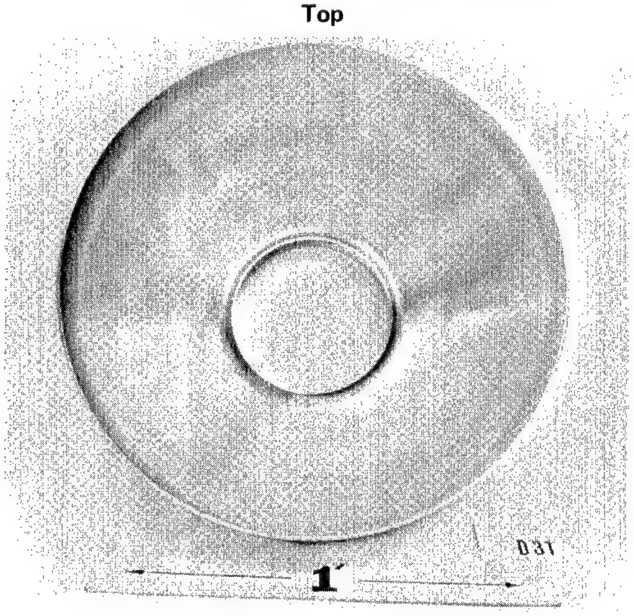


Figure 1

The H13 tool steel die was set into a 1000 ton hydraulic press, coated with graphite, sprayed with Al_2O_3, and preheated to 350 F. The spray served as a parting and diffusion inhibiting agent. Molten metal was poured into the die center at a temperature of 2900 F (±50 F). The top



Top



Bottom

Figure 2

punch, also preheated to 350 F, was lowered onto the molten metal with an initial pressure of 13,635 psi. That pressure was held for 1 second, it then was reduced to 10,910 psi and held another 4 seconds. During this squeezing, the molten metal flows into the entire die body cavity. The holding time allows the steel to solidify without forming cracks or internal porosity. After solidification, the top punch was raised and the casting removed from the die. This procedure produced consistently good castings over a laboratory run of ten parts.

Process Control Determines Quality

During experiments leading up to these final procedures, much was learned about the parameters affecting casting quality. First, **correct melt temperature** is vital. If the temperature is too low, an incomplete casting results, with excessive porosity in the upper part. When the temperature is too high, molten metal extrudes between the die and the punches and large shrinkage holes develop in the dome's thick base. The optimum temperature of 2900 F allows good, full movement of molten metal into the die with no porosity in any part of the final casting.

Pouring accuracy is a second important parameter. The metal must be poured precisely into the center of the die cavity to prevent nonuniform fill. An off center pour can also result in turbulence, splatter on the die walls, and erosion of the Al_2O_3. These events lead to defective castings and welding of the casting to the die.

A third critical element is **pour time**. Ten seconds was found to be optimum. Longer pour times allow the molten metal to enter the die in wavelets, creating layers in the final casting. Longer pours also can cause reactions between the melt and the die wall leading to possible welding, reduced die life, or distortion of die components. A faster pour results in turbulence and allows large particles of slag to pass into the die. The latter condition can also be eliminated, however, by stressing cleanliness of the melt and improving the "dams" used in the laboratory setup for holding back the slag.

A fourth process parameter affecting quality is **forging pressure**. In the lab runs, pressure was limited by the available press. However, the maximum pressure of 13,635 psi, which was dropped to 10,910 psi after 1 second, proved satisfactory. Castings forged at lower pressure were not fully developed and had internal porosity. Soviet literature has reported forging pressures up to 20,000 psi, but the IITRI results do not suggest any benefit from higher pressures than those used.

Time at pressure is a final key parameter. Pressure has been held for as long as 20 seconds for other steel castings produced at IITRI. This proved to be too long with the missile domes, however, as vertical cracks developed in the skirt. The cracks apparently resulted from opposing forces that arise when the casting contracts and the top punch expands. Reducing time at pressure to 5 seconds eliminated the problem.

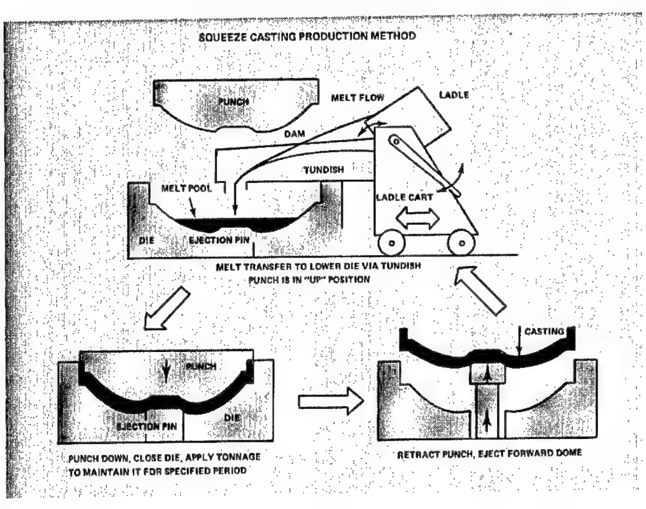


Figure 3

Adoptable As Production Process

The IITRI work indicates that squeeze casting of relatively large parts is possible as long as design requirements are reasonable. The process is sensitive to both mechanical and metallurgical parameters, but these can be controlled. The existing laboratory facilities used in this work introduced some problems. For example, the furnace was 100 feet from the press, causing a problem in controlling melt temperature. And the crucible was not designed for the exact amount of metal to be poured, making control of that factor more difficult. However, with simple modifications, the laboratory process could be adapted to short-run production of missile parts and other forgings. Fully developed, squeeze casting could offer a path to product improvement and cost reduction for a great variety of forged and cast parts.

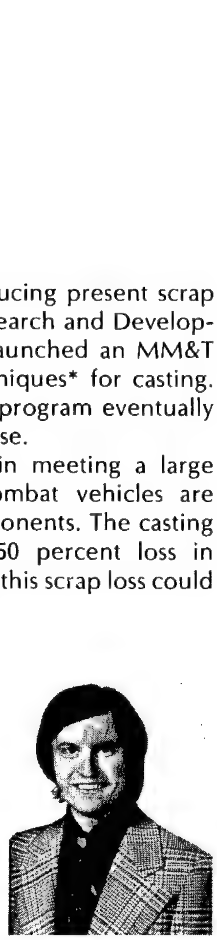
TARADCOM Looks To CAD/CAM Castings

3-D Graphic Displays

With the possibility of sharply reducing present scrap losses, the Tank Automotive Research and Development Command (TARADCOM) has launched an MM&T program to develop CAD/CAM techniques* for casting. Computer software developed in the program eventually will be made available for industrial use.

Because casting is very flexible in meeting a large number of design requirements, combat vehicles are fabricated from many cast metal components. The casting process, however, entails about a 50 percent loss in material. A means to eliminate most of this scrap loss could significantly reduce component cost.

TRAINOS K. WASSEL is a Materials Engineer at the U.S. Army Tank Automotive Research and Development Command. A recent graduate from the DARCOM Engineer and Scientist Intern Program, he is an honor graduate in Metallurgical Engineering from Wayne State University and is presently pursuing advanced studies in metallurgy. Mr. Wassel is the project engineer on a number of programs including in-house R&D efforts on metal matrix composites and nonconventional alloying techniques. He also is responsible for conducting failure analyses on tank automotive components.



Scrap Loss Lessened

The present TARADCOM program is designed to develop a computer software system that will help designers locate gates and risers in the mold in a way that will reduce scrap loss. This will be accomplished by fluid flow analysis of the casting process. The software system will be readily adaptable to production foundries.

The project is being conducted by the University of Pittsburgh, Battelle Memorial Institute, Blaw-Knox, and Mill Machinery, Incorporated. These participants will develop a CAD/CAM process for designing molds to yield a variety of uniform high quality castings utilizing N/C (numerical control) machining for fabricating patterns and core boxes. Three dimensional graphic displays will allow the designer to interact with the computer in developing the mold design. The process will incorporate heat flow, fluid flow, and stress analysis to ensure casting soundness.

To take advantage of the added potential of the CAD/CAM approach, an experimental program will be aimed at correlating mechanical properties in steel armor castings with fundamental heat flow parameters. The correlation will be incorporated in the design process to make

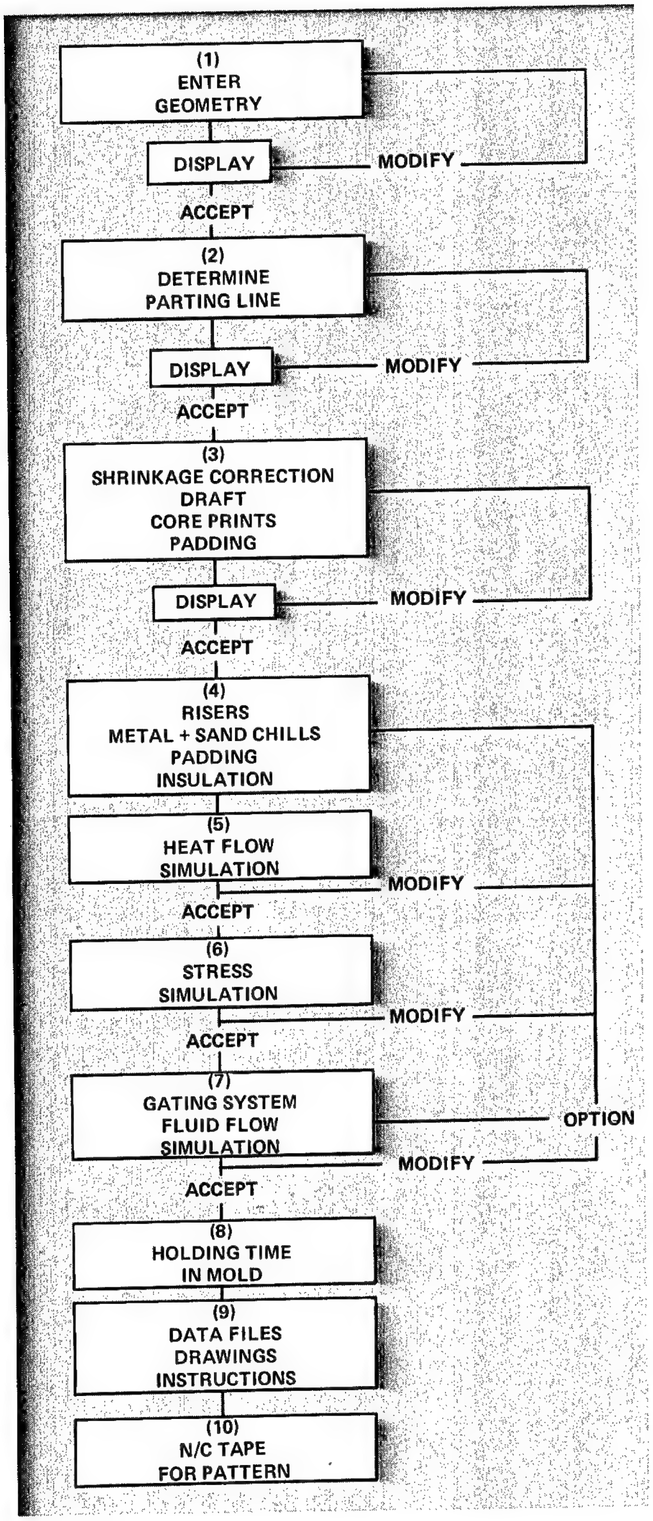


Figure 1

sure that specified mechanical properties are obtained in all critical areas of the casting. The CAD/CAM process will be designed for use by foundry engineers with no previous programming experience.

Design Sequence Established

The planned sequence in design of a mold layout will be as follows:

- The foundry engineer enters a description of the part configuration into the computer.
- On command, the computer displays the part on the interactive graphics terminal in any view requested; the engineer then can correct the design if necessary.
- The engineer indicates the parting line and faces needing draft allowances.
- The engineer indicates positions of risers, insulation, and chills. The computer calculates the volume, surface area, and weight of each segment of the casting and the dimensions of the riser.
- The computer simulates the alloy/mold system's heat flow and displays the results to indicate hot spots, local thermal gradients, and cooling rate data or expected properties (hardness, tensile strength, and impact strength). The engineer then can test alternate mold layouts until an acceptable design is determined.
- Based on results of the heat flow analysis, stresses in the casting during the last stages of freezing and on cooling to room temperature are calculated. This finite element stress analysis can be made to account for thermoplastic deformation in the metal and mold and for plastic and creep deformation. The engineer may either accept or modify the design.

- The engineer indicates the gating ratio to be tried and the computer determines dimensions of the gating system and displays the system on the screen.
- The computer specifies the necessary holding time after pouring for shakeout of the casting.
- The computer specifies the acceptable pattern, stores it in a data file, and determines cutter paths for N/C machining of the pattern.

This design sequence is outlined in Figure 1. The computer software system will be hardware independent and applicable to a variety of casting processes, materials, and casting sizes and configurations.

Demonstration Project Planned

The effectiveness of the CAD/CAM process will be demonstrated by producing a pattern for the torsion bar housing for the XM1 tank (Figure 2). This part represents a typical case study of designing and developing a casting procedure for a new part. During process development, porosity was encountered in an area of the housing where two barrel sections blend together. A number of trials of gate and riser locations were made to eliminate this porosity. In addition, radii were enlarged to provide increased metal flow into the areas containing porosity. Nonetheless, it has been necessary to grind and weld repair the castings to meet the required specifications. This part presents an ideal problem to test the utility of the CAD/CAM process.

Torsion bar housing castings will be made using the CAD/CAM manufacturing design, inspected, machined, and heat treated to meet the drawing specifications. The project team will analyze costs for producing torsion bar housings utilizing the CAD/CAM system. This analysis will provide the basis for introducing the process into other production applications.

Upon completion of this effort, the computer software developed will be made available for industrial use. A 10-15 minute film report on using the system will also be made available.

*Computer aided design/computer aided manufacture.

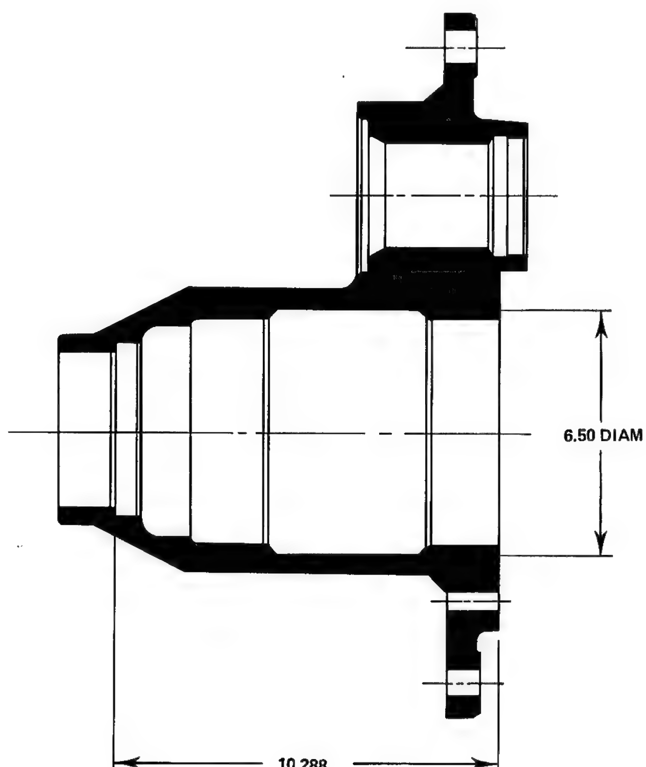


Figure 2

Impossible Technique Coming Of Age?

Color Inspection of Textiles

Just what is olive drab? Or khaki? Simple enough, you may say—they're colors that anyone can recognize. But it's not so simple when it comes to accepting material for Army uniforms. Since material for different parts of uniforms usually comes from different suppliers, color matching is very important. And distinguishing exactly between different shades can be very difficult—and controversial.Contractual disputes over color are not uncommon. The failure to properly match color—or to agree that it matches—is very costly to the military, to manufacturers, and, ultimately, to the taxpayer. The U.S. Army Natick R&D Command (NARADCOM) is out to cut off that expense by developing a reliable, objective system by which to measure color.

Color acceptability always has been and still is based on subjective visual measurements. Despite all the advances in color science, scientists haven't yet found computerized optical instruments to supplant the subjective visual method. But as sensitive as the human eye is to color, it is not consistent. No two people with normal color vision respond the same to a particular color stimulus. Nor does the same individual respond the same under different conditions. Thus, color acceptability has been a most troublesome problem in textile procurement. With the Department of Defense spending more than half a billion dollars each year for textiles and clothing items, the losses from contractual disputes and rejected lots of material because of color can become significant amounts quickly.

Effective Program Under Way

An ongoing research project at NARADCOM may solve these problems. Now well into the second of four phases and marked with success to date, this program seeks a quantitative, objective system for inspecting colored fabrics.

During the first phase, optical analyzers were surveyed and evaluated and at least one reliable, commercially available instrument was identified. The second phase involves design of a system, including modification in software programming of the instruments. During the third phase, a prototype system will be assembled and evaluated. The fourth phase will involve a field trial of this system.

ALVIN O. RAMSLEY is Chief, Countersurveillance Section, U.S. Army Natick R&D Command (NARADCOM), where he is responsible for the Command's camouflage program and the objective aspects of the color of textiles. He holds a B.S. in chemistry from Houghton College and an M.S. in chemistry from Columbia University. He is a member of the Optical Society of America, the Inter-Society Color Council, the American Chemical Society, Sigma Xi, and several other scientific societies. Mr. Ramsley was awarded the Command's Research Director's Award for his studies of the relationship of certain camouflage measures to the protection of the soldier against the thermal effects of nuclear weapons. He also presented a prize winning paper at the Army Science Conference on the use of infrared fluorescence in certain camouflage applications, a technique virtually unknown previously. In addition, he participated in the design of the D-38 colorimeter, one of the instruments mentioned in this paper.

Tight Control A Must

Why is color control so important for the military? To begin, military procurement and use of textiles differ substantially from practices in the civilian economy. A garment maker for the civilian trade usually manufactures an entire garment—trousers, jacket, and vest, for example—from one lot of fabric produced by one supplier. Tight color control is important within a lot, but is usually less important from lot to lot.

The situation is very different with military procurements because many separate manufacturers, often using different production methods, furnish the fabrics. One manufacturer may produce the uniform jacket from one lot of fabric and another the trousers from a different lot. Therefore, it is essential that variations in color be minimized and governed by established standards. Mismatched lots of fabrics result in mismatched uniforms and a nonmilitary appearance.

A further consideration is the importance of camouflage for combat clothing. The colors of combat clothing and equipment are carefully chosen to aid in concealment in particular environments. Thus, careful control of color is an important factor in enhancing both troop morale and combat effectiveness.

Costs Down . . . .

A reliable color inspection system would provide two major benefits. First, it would virtually eliminate contractual disputes and consequently lower the costs. As many as three or four serious disputes over color acceptability occur every month, costing the Government both time and money. Such disputes also delay deliveries and payments and pose the problem of how to dispose of nonstandard materials.

The costs of disputes to industry, though difficult to estimate, probably exceed those to the Government. Government penalties for only partial fulfillment of a contract can eat into already narrow profit margins. A manufacturer can try to retrieve losses by attempting to sell unaccepted material in other markets, but there are only so many makers of hunting outfits. Or he can reprocess and redye a material to a darker color—unless it is water repellent.

Quality Up . . . .

The second, perhaps greatest benefit to be derived from an effective color measurement system would be improved quality through use of the color inspection system for on-line production control. Although such an arrangement is well down the road, it is the logical next step after developing an objective color measurement system for the Government. There is no question that once the inspection system is operational it can be modified for use on a production line. Then, if the color wanders off shade during manufacture, automated feedback would immediately specify corrective action.

Visual Measures Long Accepted

As mentioned, the acceptability of colored materials always has been judged visually, a method that still is in general use. Optical instruments simply have not yet been able to surpass the human eye—an extraordinarily sensitive optical instrument—for judging differences in color. However, color research has provided many refinements in the visual methods, especially in the past 50 years. Two of the more significant advances have been the standardization of light sources for viewing and the establishment of physical tolerance standards. Tolerance standards are set by specimens illustrating the maximum acceptable departures in color from a target standard. Another improvement has come in detection of various kinds of color blindness. Persons with such defects are excluded from making color judgments for the Government.

Operation of a visual inspection system is straightforward. Figure 1 shows a typical viewing booth now used by the Defense Logistics Agency for visually judging color acceptability of textiles. A standardized light source that can simulate either daylight or interior lighting allows a person referred to as a "shader" to compare a series of samples from a production lot with the target standard. In borderline cases, the shader also will compare the samples with tolerance standards. If a production sample does not appear to match the target standard more closely than the tolerance standards, it is rejected.

Figure 1

Systems Have Shortcomings

For many production runs, a well managed visual inspection system works well and presents few problems. In other cases, however, problems arise when a sample appears to match the standard under daylight but looks quite different under artificial light. Figure 2, for example, shows reflectance curves for two olive green fabrics that match fairly well in daylight. Under tungsten light, however, Sample A appears much more red than B.

A further problem with visual evaluations is that no people with normal color vision respond the same way to color stimuli. One observer may judge Sample A in Figure 2 an acceptable match for B in daylight, while the same sample is seen as "red" or "full" by another observer under the same light. These differences among normal observers are more pronounced because of differences in age.

Although consistent visual results usually can be obtained with the average of a rather large panel of normal observers, there are obvious economic drawbacks to inspection on that basis.

Objective Measurement Needed

How can the measurement system be improved? The Commission Internationale de l'Eclairage (CIE)—or International Commission on Illumination—has standardized the spectral distribution for the illumination sources of concern in judging color and color differences. The need now is for a sufficiently precise and stable optical instrument to reliably characterize the spectral reflectance.

Commercial instruments for measuring color appeared as early as 1939, and research in design of these colorimetric instruments led to gradual improvement in their performance. Although these instruments meet the in-house needs of individual laboratories, dye houses, and textile mills, they generally are not considered sufficiently reliable for multiparty contractual matters.

In about 1970, however, a major step forward was taken with interfacing of minicomputers with spectrophotometric equipment. These systems provided far greater precision in color measurement, although at rather high cost. Subsequent evolution of microprocessors stimulated some of the optical instrument makers to design small spectrophotometers in which the microprocessor quickly calibrates, standardizes, and computes without sacrificing precision. When NARADCOM's project began in 1977, two such instruments were on the market—the Hunter D54 and the Macbeth MS-2000. In January, 1978, Diano also began to market such a spectrophotometer. All three instruments are competitively priced in the $17,000 to $20,000 range, about one-third the cost of earlier instruments similarly equipped.

The NARADCOM Research Project

With the advent of these instruments, dependable, objective measurement of color now appears feasible. NARADCOM has set out to develop a reliable system through the four phase approach mentioned earlier. The objective is a color measuring system that will meet the following criteria:

- Be at least as sensitive as the eye in detecting small color differences.
- Be more consistent than the eye in qualitative and quantitative definition of these color differences.

- Be adaptable to a wide variety of surface textures.
- Use CIE standardized data.
- Provide rapid, automatic calibration and computation through an interfaced microprocessor.
- Provide a printout of colorimetric data in terms of daylight, tungsten light, and fluorescent light and computation in terms of acceptability limits.
- Be sufficiently reliable, fast, simple, inexpensive, and rugged for practical use in an industrial environment.

In Phase I, the available commercial spectrophotometers were evaluated for reliability. The analysis of instrument stability and repeatability was based on color measurement of a wide variety of specimens, including textile, plastic, paint, and ceramic surfaces.

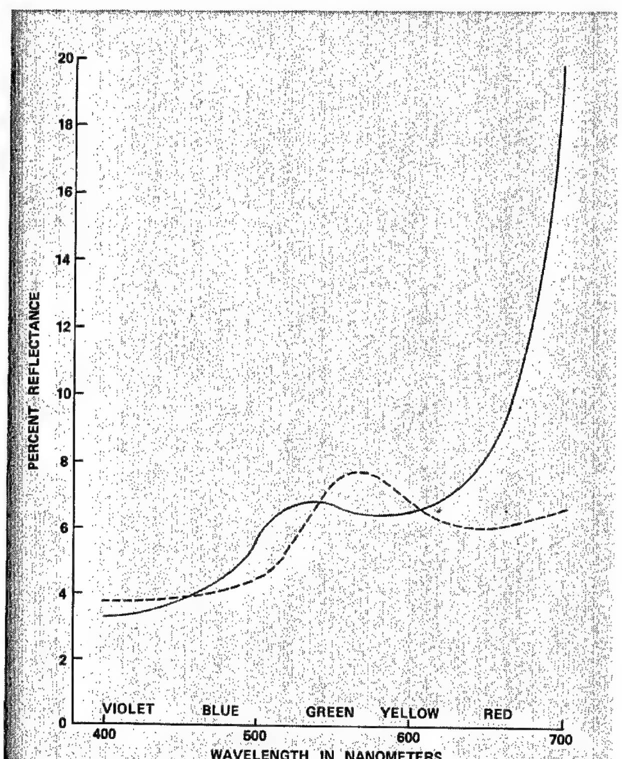


Figure 2

System Modifications Required

Phase II, now in progress, is concerned with system design. Changes in microprocessor programming to obtain the necessary acceptability data are being identified. Although no fundamental optical modifications to commercially available equipment are anticipated, early research in this phase identified the need for certain modifications in the software programs to give some computational capability beyond that now provided. For example, the programs must provide automatic averaging of multiple readings, a statistical measure of dispersion about the average, changes from one set of standard colorimetric data on light sources to another, and a yet to be determined definition of acceptable color differences.

During Phase III, two prototype systems will be assembled and evaluated. One unit will be located at NARADCOM and the other at the Defense Personnel Support Center, Philadelphia, where inspection now takes place. Parallel measurements of at least one shade will be made on enough specimens to establish reproducibility of the two units. The measurements also will be correlated with visual grading by a panel of observers. Expected minor modifications in microprocessor programming and in measurement procedures will be made and verified during this phase.

Real Production Test Final Step

In Phase IV, the system will be validated in a practical environment. To prepare for Government coordination with industry, a third unit will be acquired and placed in a contractor's textile mill during large procurements. The system will be used to grade production samples for color at the mill, at the Defense Personnel Support Center, and at NARADCOM. Decisions based on use of the system will be monitored using present visual methods.

Whether or not this program is completely successful in meeting its objective, it promises to provide a significant step forward in objective measurement of color differences.

Higher Quality Through NDT Training

Automation Not Always The Answer

In an ideal world, we would automate all of our nondestructive testing (NDT) operations—turn inspection over to the computer—thus eliminate human element once the computer was programmed. But the fact is, the human element is still needed in many cases, fallible though it may be. There are some judgments automated equipment simply cannot make, at least not at a reasonable cost. What is needed then is assurance that the persons involved when NDT cannot practically be automated are well trained and properly qualified to make these judgments.

The Army Materiel Development and Readiness Command (DARCOM) has a certification program designed to provide such assurance. When this program is fully implemented (which will take several years), each element within DARCOM will operate its own NDT training and certification program within an overall framework administered by AMMRC. The expected result is an overall cost savings and improved product quality. The DARCOM program could serve as a model for others with widespread operations who seek to establish or upgrade certification procedures.

NDT Important To User Satisfaction

DARCOM has always recognized the importance of quality to user satisfaction and has continuously pursued programs to insure high reliability. One recent positive step toward user satisfaction was the initiation of Project Hand Off in 1975. A primary objective of this project is to ensure that materiel issued to users is free from latent defects. This is where NDT enters the picture with its ability

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to detect defects that are not readily or immediately apparent during visual or performance checks.

For example, an inclusion in the combiner gear of a helicopter power train may cause no problem during hundreds of flying hours. Yet, a sudden severe stress on that portion of the gear could cause instantaneous failure at any time, crippling the aircraft and possibly causing its loss as well as the loss of those in it. Failures of this nature (and they do occur) amplify the importance of NDT in ensuring materiel quality.

As a result, our emphasis is shifting from sampling to 100 percent acceptance inspection wherever possible. In today's high production environment, efforts to implement requirements for 100 percent inspection have created a heavy reliance on automated NDT. In many cases within DARCOM, the Army Materials Testing Technology Program has been providing the technological advances necessary to develop unique automated NDT systems. Several examples were discussed in a previous issue of the ManTech Journal.

Automation Not Always Practical

In the majority of cases, however, automated NDT techniques are still either not feasible or are too expensive. For example, rebuild inspection of welds and surveillance inspection of rocket motors are applications where non-automated NDT is the most practical solution to inspection requirements.

The situation may vary from item to item, but, within the spectrum of all DARCOM materiel, examples of non-automated NDT are found during all materiel life cycle phases—R&D development of armor, production of cannon tubes, rebuild of tanks and helicopters, and surveillance of munitions. These are cases where non-automated techniques have proven to be the best answer. It is not a matter of automation simply not having been considered yet.

In these nonautomated applications, DARCOM personnel operate the NDT equipment and make judgments regarding the acceptability of the item being inspected. DARCOM also employs many inspectors in contractor's facilities to monitor the NDT performed and make sure that the contractor reaches the same decision that the government would regarding the acceptability of items produced.

Proper Training Essential To Quality

To perform their duties effectively, these people must be properly trained and qualified. This has been a long time need. In 1940, DARCOM established the Metals Inspection and Nondestructive Testing Training Program at AMMRC in order to provide NDT training assistance to DARCOM elements. This school now offers the following courses:

- Introduction to NDT
- Magnetic Particle and Liquid Penetrant Testing
- Radiographic Testing
- Ultrasonic Testing
- Ultrasonic Testing of Welds
- Weld Inspection

Except for radiographic testing, which runs 80 hours, these are all 40 hour courses.

The courses combine classroom lectures with laboratory sessions that enable the student to operate the equipment with close supervision and instruction. This training is offered free of charge to DARCOM personnel. Classes are held both at AMMRC and, to a limited degree, on site. Although the school staff level has remained constant, attendance and requests for spaces have been growing, reflecting the increasing awareness of the importance of NDT.

Certification Must Follow Training

Training alone is not enough, however. There must be some assurance that the person has absorbed the training and is indeed qualified to conduct the subject tests and make the necessary judgments. Unlike most mechanical and chemical tests, nondestructive techniques do not produce a direct readout of the parameters of interest—cracks, porosity, bonding, etc. The desired information must be obtained by interpreting the display, whether it be a radiograph or a cathode ray tube trace. This interpretation requires a judgment by the test operator in reaching an accept/reject decision. The accuracy of this decision is especially important since any problems resulting from a latent defect will not appear until the materiel is in service.

Recognizing this circumstance, both the Department of Defense and industry have placed special training and experience requirements on NDT personnel. Personnel meeting these requirements are certified to the appropriate level of proficiency.

Table 1 lists just a few of the DoD standards and inspection documents that require certification of NDT operating personnel. Two common references specifying special training and experience requirements for NDT personnel are cited in these documents. One of these is Mil Std 410, Nondestructive Testing Personnel Qualification and Certification. The other is the American Society for Non-

Document Number	Title
MIL-STD-271	NDT Requirements for Metals
MIL-STD-00453	Radiographic Inspection
MIL-I-6866	Penetrant Inspection Method
MIL-I-6868	Magnetic Particle Inspection Process
TM-43-0103	Nondestructive Inspection Methods
MIL-C-6021	Classification and Inspection of Castings
MIL-W-21157	Carbon and Low Alloy Steel Weldments
TM55-1520-210-34	DS and GS Maintenance Manual for Army Model UH1-D/H Helicopter
TB55-1500-206-20-21	UT Inspection of 540 Series Main Rotor Blades

Table 1

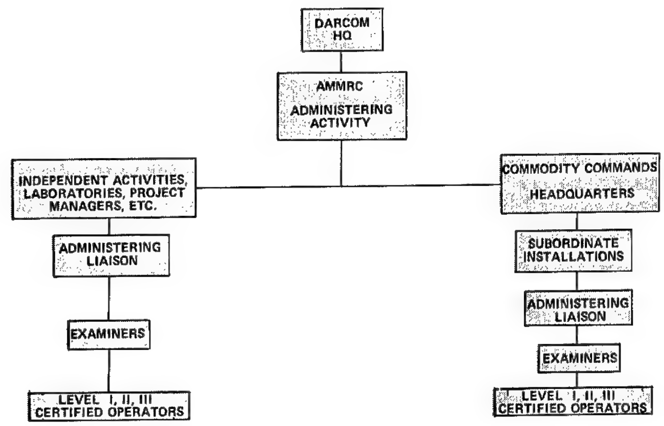


Figure 1

destructive Testing Recommended Practice No. SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing.

DARCOM Certification Program

In compliance with the DoD requirements, a centralized NDT certification program has been established within DARCOM under the guidelines of DRCR 702-22, Qualification and Certification of DARCOM NDT Personnel. An organization chart for the program is shown in Figure 1. The training and experience requirements set forth under DRCR 702-22 meet or exceed all the minimum requirements of both government and private industry. The program covers radiography, ultrasonics, magnetic particle, liquid penetrant, and eddy current techniques.

The DARCOM Certification Program, in line with other NDT programs, encompasses three levels of proficiency. These levels are defined by duties in Table 2. One place where the DARCOM program differs is the use of a Level I Special Category, wherein personnel are authorized to accept items in accordance with one procedure. There are frequent instances within DARCOM where a person's duties will include the performance of one nondestructive test. For example, the TSARCOM Field Service Inspectors perform periodic ultrasonic inspection of tbe 540 Series main rotor blade. For these personnel, the training and experience requirements are tailored to the specific procedure to be performed. Training and experience requirements for personnel at the other levels are listed in Table 3.

Levels of Qualification	Major Responsibilities
Level I	Prepare Parts Set Up Test Execute Test
Level I (Special Category)	Prepare Parts Set Up Test Execute Test Limited Accept/Reject
Level II	Calibrate Equipment Interpret Test Results Apply MIL Specifications and Standards Report Test Results Train Level I Applicants
Level III	Establish Test Techniques Interpret Specifications and Standards Evaluate and Approve Test Techniques and Procedures Examine Level I, II, III Applicants

Table 2

Persons who complete the prerequisite training and have the necessary experience are eligible to take a series of three examinations leading to certification. The examinations include a general exam covering (1) the basic theory of the method in which certification is sought; (2) a specific exam covering the application of the test method

Method		Radiography			Ultrasonic			Magnetic Particle			Liquid Penetrant			Eddy Current		
Level (NS-Not specified in DRCR)		I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
High School Graduates and above	Training hours	80	40	0	40	40	0	24	8	0	16	8	0	48	12	0
	Experience	NS*	1 year**	4 years**	NS*	1 year**	4 years**	NS*	6 months**	4 years**	NS*	6 months**	4 years**	NS*	9 months**	4 years**
Grammar School Graduates	Training hours	80	100	0	40	80	0	24	24	0	16	16	0	48	24	0
	Experience	NS*	1 year**	4 years**	NS*	1 year**	4 years**	NS*	6 months**	4 years**	NS*	6 months**	4 years**	NS*	9 months**	4 years**

* On-the-job training at the level of certification.
** Experience gained at next lower level.

Table 3

to the commodity with which the applicant is working; and (3) a practical exam covering actual performance of the test. Upon successful completion of these exams, an operator is certified.

Implementation Under Way

The DARCOM NDT Certification Program currently is being implemented at forty installations and activities where several thousand personnel eventually will be participating. The first step in the implementation plan was appointment of administering liaison personnel at each participating element for local coordination and management. Next, a limited number of Level III "Grandfather" certifications were issued to 17 well qualified applicants at various DARCOM elements. Eight of these persons were appointed as examiners to initiate the process of certifying other candidates for examiners at each of the participating elements.

Examiners are generally Level III personnel, who are responsible at the local level for the technical portions of the program—such as developing examinations and on the job training programs. Currently, examiners have been certified at nine DARCOM elements where they are certifying NDT personnel with adequate training and experience to qualify. For those personnel lacking sufficient training, appropriate programs are being established. As would be expected, implementation is much closer to completion at those elements that have examiners.

Independent Operation the Goal

It now is apparent that once the process of identifying currently qualified personnel to fulfill the responsibilities of examiners is complete, approximately half of the participating elements will require upgrading in NDT expertise before they can function with some degree of independence within the program. Independence is and has to be one of the major objectives of the DARCOM Certification Program. Each DARCOM element is solely responsible for the quality of its product and is, therefore, ultimately responsible for the performance of its personnel. Accordingly, when the program is fully implemented, each employing element will have to certify its own personnel. AMMRC, as the Administering Activity, does not have the resources necessary to directly support a large number of elements through on-site training and examiners.

Where upgrading is required, individual plans of action must be established to identify the necessary formal classroom training and on the job training. These plans will take into account the relationship of NDT to the mission of the installation or activity and the existing level of expertise required. These factors will vary from element to element, and each element will proceed toward implementation of a viable certification program at its own pace.

It is probable that full implementation of the program within DARCOM will require several years. The rewards in terms of cost savings and improved product quality promise to be worth the effort.

Computerized Test Replicates Actual Service

Fast, Reliable, Low Cost Method

Reliability is an often referred to and increasingly important concept in our space age technology—and with good reason. Consider, for example, the case of missile fuzes. In the past, the reliability of fuzing for low cost, high volume ammunition fuzes was important, but really not critical. If an occasional round failed to function, the cost was relatively small. Thus compromises and approximations were acceptable in qualification testing.

This is not true today, however, with the high cost missiles we use to carry sophisticated payloads, either as weapons or space packages. The cost of a malfunction with one of these missiles can be tremendous in lives as well as dollars. Near 100 percent reliability of the fuze is a must. To obtain such reliability, qualification test conditions must exactly replicate service requirements. The compromises of past methods cannot be tolerated.

To meet these greater demands in one important test area, Harry Diamond Laboratories (HDL) has developed a computerized process for vibrational shock testing of missile fuze components. The system automatically simulates a wide range of conditions in order to match the exact service environment of a given part. This eliminates the risk of failure associated with the "equivalent" test methods of the past. Test environments that were previously impossible or impractical to replicate are easily simulated either in the laboratory or in production.

Autosynthesis Achieved

This innovative technique is fast, accurate, low cost, and repeatable—and it provides a permanent record of test data. Computer programmed shock testing takes just a few seconds—no impact computations or lengthy setup operations are needed. Test parameters are permanently retained on punched tape. These tapes can be rerun as often as needed, keeping costs down, improving efficiency, and making the procedure highly reliable. The computer records the results of all test parameters and prints them out immediately after the test.

Potential savings in testing costs are quite significant. Without the capability for simulated testing, dynamic tests would require actual launching of a missile costing between $50,000 and $100,000 depending on the missile system. Practically all of this expense is saved by the low cost computerized shock test. The concept is applicable to vibration tests of a wide variety of systems—warheads, rockets, helicopters, planes, track vehicles—whose vibration and shock environment falls within the capabilities of the test equipment.

ABRAHAM (AMI) FRYDMAN is a supervisory project engineer in the Environmental Engineering Branch of the Harry Diamond Laboratories with primary responsibility for test simulation technology. He received his BME (1966) and MME (1970) from the School of Mechanical Engineering at the City University of New York. He held several RDT&E engineering positions with the NASA /Apollo Program and the Navy/Advance Destroyer Communication Program beginning in 1966. At HDL since 1973, he has been developing advanced testing and simulation methods verified by structural dynamics techniques to achieve improved similitude and more efficient testing during product qualification. Mr. Frydman is a member of the ASME and the EIS and has participated in technical sessions and forums sponsored by these societies on shock/vibration topics. He is the HDL representative to the DOD/Fuze Engineering Standardization Workgroup where, as a committee member, he is engaged in the generation of test standards for tactical and transportation vibration and safety testing.

The HDL test method utilizes a Transient Waveform Control (TWC) technique. A digital minicomputer completely controls the test—frequency, duration, amplitude, automatic filter equalization, safe/abort limits—with no human intervention. The goal at the outset of development was automatic synthesis of the product's service environment. That goal has been achieved.

HDL's Role

Development of such innovative techniques to meet new and difficult testing requirements is an essential part of the HDL role in MTT. Harry Diamond Laboratories regularly tests and validates a great variety of ammunition and missile fuzes. This function fits well with the HDL mission—to take these products through design, development, and preproduction into readiness for large volume production. This responsibility requires that HDL be up to date in all modes of environmental testing in order to fully support ongoing in-house programs and to assist other agencies and Commands as the need arises. Vibration and shock testing is only one part of an extensive environmental test facility HDL has developed in keeping with this responsibility.

MTT Funds Help

When the need for more exacting qualification of missile fuzes arose several years ago, HDL had to find the means to increase the precision, fidelity, and efficiency of replicating complex launch and flight vibration/shock environments. To help meet this urgent need, HDL received MTT program support to augment existing hardware and develop computer software for implementation on an existing computer controlled electrodynamic shaker system. The intent was to develop the TWC test method and incorporate it into the process for qualifying production missile fuze material.

Computer test equipment and digital servocontrol techniques were designed so that various complex, service related environments could be reliably simulated on the electrodynamic shaker. The design also allowed completion of qualification tests without disrupting production line schedules.

The electrodynamic shaker is shown in Figure 1 and the control hardware in Figure 2. Figure 3 is a simplified block diagram of the TWC system. By using digital minicomputers, sophisticated control drive techniques have been coupled with dynamic (real time) testing. Fast Fourier Transforms (FFT), Inverse Fast Fourier Transforms (IFFT), and digital servocontrol techniques are used to synthesize complex vibration/shock signatures on the shaker. Through normalization techniques, a transfer function representing the required environment is derived. This function becomes the shaker drive signal when converted from frequency domain to time domain voltage representation. It is converted from digital to analog representation, smoothed, and amplified before transmittal to the shaker.

During testing, the drive voltage function undergoes constant iteration through refinements of the transfer function. Variation between the prescribed and synthesized amplitude is constantly controlled, insuring replication of the desired environment.

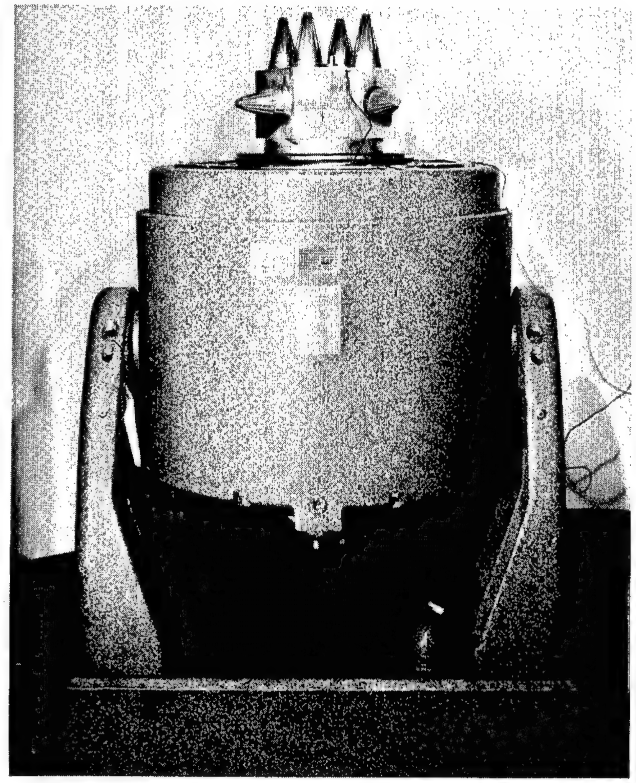


Figure 1

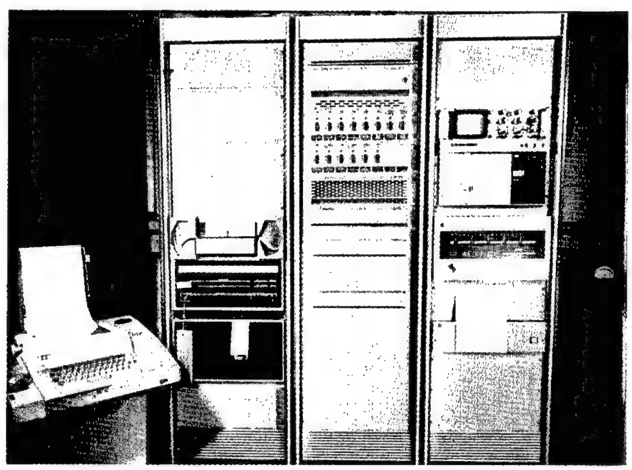


Figure 2

Tape Drive Used

To operate the system, all test requirements and abort limits (needed to safeguard against catastrophic failure) are programmed on a coded test tape. This tape is generated during an interactive question and answer routine—using conversational language—in which the test system controller queries the operator for test information.

The coded tape provides a permanent record of the prescribed vibration transient and can be reused to repeat the test when needed. The program also allows for a time delayed, repeated execution of the specified transient to automatically comply with the formal three pulse per axis

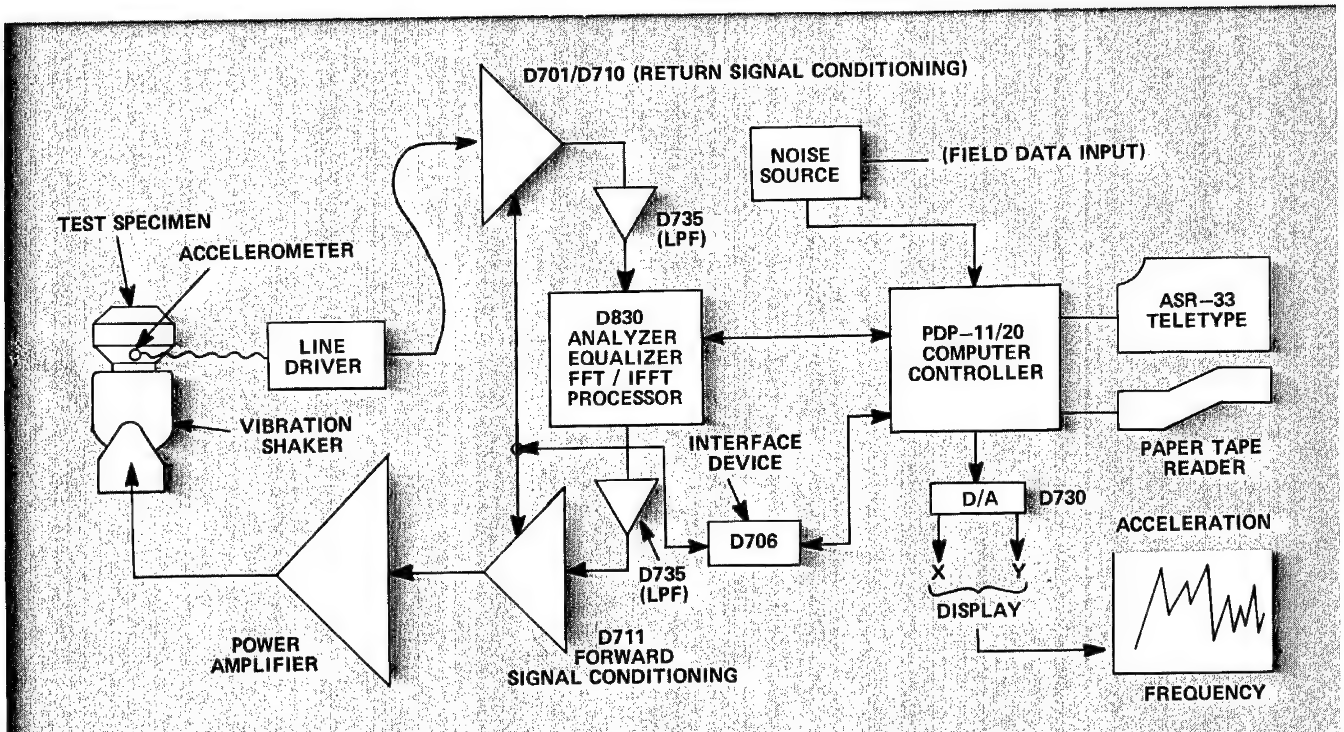


Figure 3

requirements commonly invoked in military test standards (i.e., Mil Std 331A and 81 0C). When the test is finished, the computer will on command print out complete alphanumeric data on all test parameters as executed.

Accuracy Confirmed

Accuracy of the system is illustrated in the accompanying recordings of vibration transients. Figure 4 shows an acceleration time record taken at motor ignition aboard an in-flight PATRIOT missile. Figure 5 shows the synthesized waveform of the same event reproduced on the TWC system, replicating axial vibrations in Figure 4 over the time interval 0.657 to 0.682 seconds. The average error over the useful portion of the transients after noise effects have been discounted is less than 10 percent.

The TWC method also has been used to successfully replicate other standard waveforms and complex field shock signatures ranging up to 50 g peak acceleration and 20 to 25 millisecond duration. The test technique can be further extended to cover up to 500 g peak acceleration and 1000 millisecond duration. System control error for a variety of test cases averaged less than 10 percent over the testing range. More precise amplitude resolution and frequency control now can be achieved due to an increased number of filters (up to 512). All indications are that this low cost yet highly reliable technique offers a realistic method for vibration/shock testing of missile fuzes.

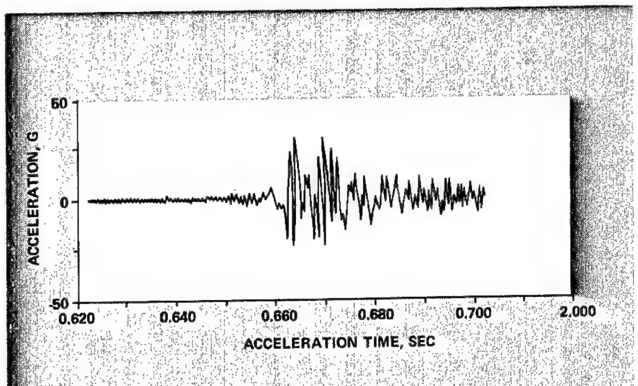


Figure 4

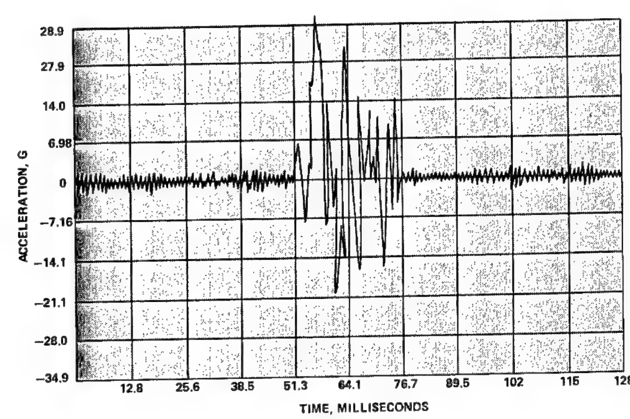
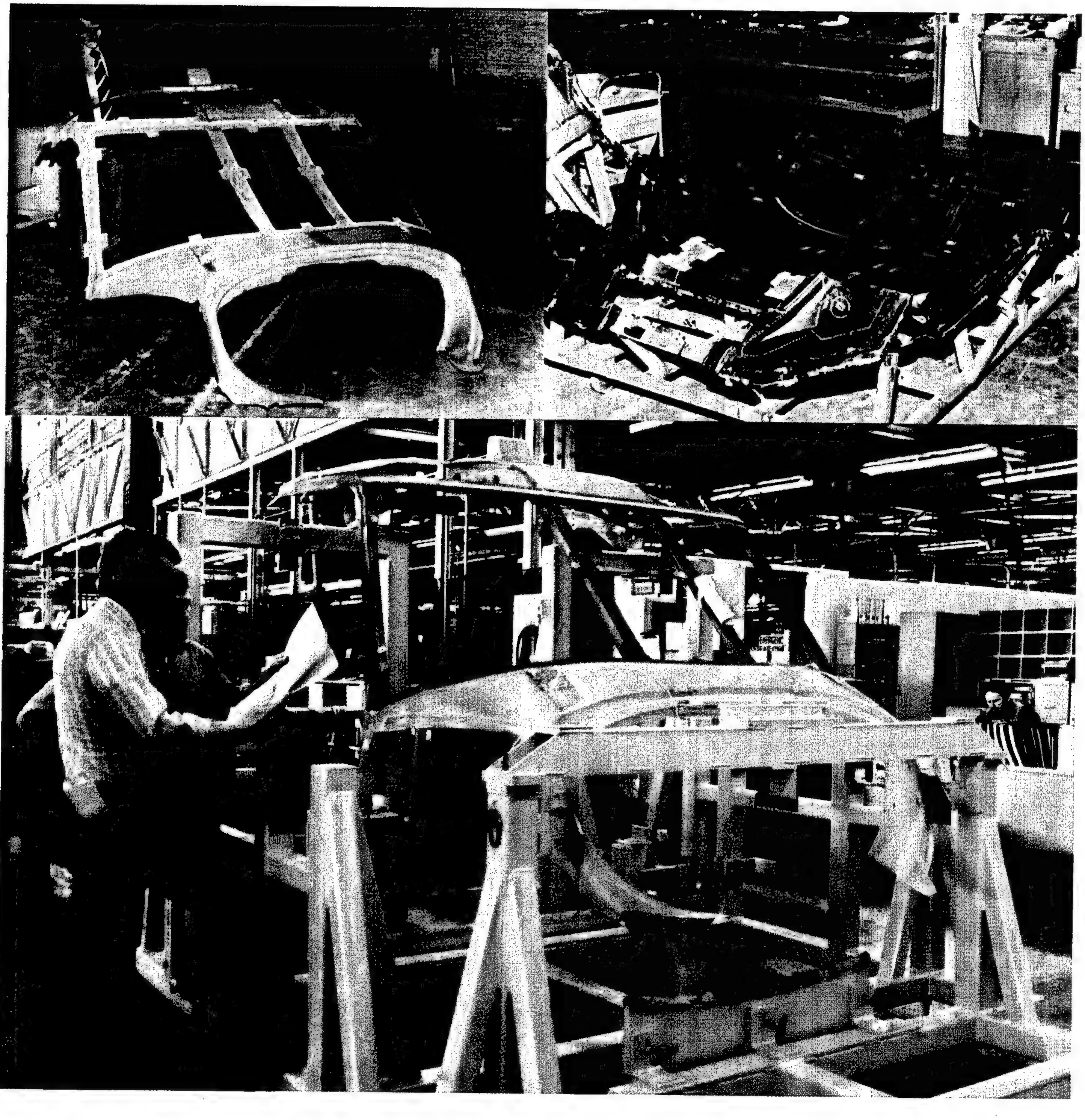


Figure 5

US Army
ManTech Journal

Composites Changing Fabrication

Volume 3/Number 4/1978



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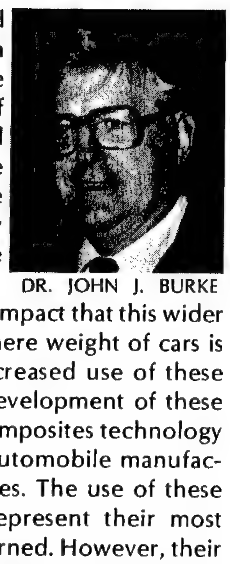
US Army
ManTech Journal

Contents

ABOUT THE COVER:

A totally new concept in composite fabrication became reality with the development by Sikorsky of the "skin skeleton" technique exemplified by these photographs. The canopy structure shown is that of the UH60A helicopter and represents a remarkable breakthrough in precision molding of composite materials. The mold assembly is shown above right and the untrimmed component produced in the mold is shown above left. The finished canopy structure is seen in its assembly jig below. Near perfect congruence of two highly curved, complex nested parts is achieved—reflecting a true milestone in composite fabrication technique.

Comments by the Editor


DR. JOHN J. BURKE

Structural mechanics is undergoing one of the most profound changes in the history of modern design and manufacturing with the dramatic new uses being made of composite materials. This issue of the Army ManTech Journal provides an excellent perspective of some of these new uses that the Army is implementing in its varied activities, including not only aircraft structures, but also bridge structures for field use, and internal structural and high temperature applications in aircraft turbines. The Army also has the responsibility of establishing workable standards for its materials, as depicted in the article on quality control of organic based composites.

A scan of late developments in the industrial arena reflects the impact that this wider use of composites is having, especially in the automotive field, where weight of cars is planned to be halved within the next two years by markedly increased use of these lightweight strength materials. The many years of research and development of these materials by the aerospace industry has created a broad range of composites technology relating to their physical and structural properties, enabling the automobile manufacturers to implement massive utilization of these unusual properties. The use of these materials in the mass production of vehicles ultimately may represent their most significant application insofar as benefit to the most people is concerned. However, their further application in commercial aircraft will provide greatly increased economy, safety, and durability, thereby benefitting vast numbers of people.

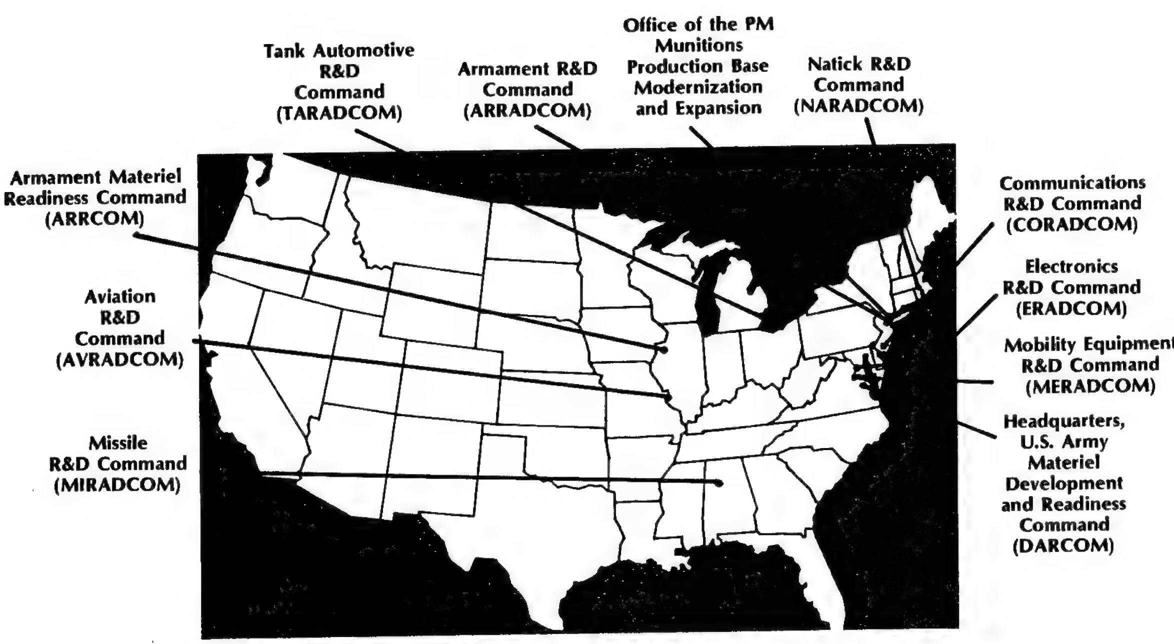
This issue marks the end of another year of publication for the ManTech Journal, one which witnessed the distribution of issues featuring the Army Aviation Research and Development Command's new manufacturing techniques, materials testing developments in the Army, and also advanced casting techniques being implemented by the Army. We believe it appropriate to feature the Army's latest developments regarding composite fabrication techniques to end the year in which composites experienced their most far reaching impact to date on our populace. With the favorable energy utilization that characterizes their manufacture and application, and also the large weight reductions resulting from their greater strength/weight ratios, we undoubtedly will see greatly increased application of them far into the future.

A special feature of this issue on composites is the article on the Army's Engineering Design Handbook series produced by the U.S. Army Materiel Development and

Readiness Command (DARCOM). Though primarily conceived for use by specific DARCOM agencies, we believe the handbooks are also useful to Army contractors and to engineering agencies or individuals concerned with broad, general applications. Much of the technical data contained in these volumes is of unique character and is simply unobtainable elsewhere.

Our topics for the coming year will include issues featuring Army and industrial achievements in joining, electronics, CAD-CAM, and group technology. The latter two topics are very much in our future with manufacturing technology, and the Army has some interesting and informative programs under way that we will be telling readers about.

DARCOM Commands Actively Implementing New Manufacturing Technology Methods



Quality Control of Composites

Analysis Technique Developed

DR. BERNARD M. HALPIN, JR. is currently a group leader in the Composite Development Division of the Army Materials and Mechanics Research Center, with an overview of the processing and prototyping of organic materials in the Organic Materials Laboratory. He has been active in the field of composites since 1971, having started at AMMRC in 1969 as a synthetic organic chemist. He holds a B.S. in Chemistry from Merrimack College and Ph.D. in Organic Chemistry from Boston College.

Although the use of organic based composites in structural applications is steadily increasing, a quality control problem remains. Nondestructive evaluation of the composite products is difficult, with no universally accepted method. Therefore, rigid control of the materials used to fabricate the products is imperative.

Product Stability Assured

Work at the U.S. Army Materials and Mechanics Research Center (AMMRC) has demonstrated the value in this regard of both high pressure liquid chromatography and Fourier transform infrared spectroscopy. These methods have been used for chemical analysis of epoxy resins, resin impregnated reinforcement fibers (prepregs), and composites. Although initial costs for these analytical systems are rather prohibitive at this point, continuing efforts to refine the techniques promise reduced costs in the future. As these costs drop, they can be repaid many times by eliminating the high incidence of part rejections often traced to improper starting materials. Either process can be used to make sure that no significant changes in formulation occur over the lifetime of the product.

AMMRC has used the two techniques individually and together to characterize epoxy resin formulations utilizing 3M's 1009 and SP-250 formulations and Reliable Manufacturing's RAC 7250. These characterizations have included degree of cure, aging of prepreg, effects of cure conditions on the oxidation stability of the resin, products of degradation attack, and effect of processing on the chemistry of the resin systems. AMMRC has demonstrated that the use of either system can easily detect problems now missed by both suppliers and users.

Study Explains Deterioration

Although a large number of resins and prepreg systems have been evaluated at AMMRC, the bulk of the data amassed to date concerns the three prepreg systems mentioned above. Before AMMRC's work with 1009, a good deal of mystery surrounded the environmental deterioration of composite materials. Study after study had produced reams of highly specific data; for example, System X will not degrade as severely as System Y when exposed for 5 years in

Panama in an unpainted condition. But nothing explained why this was true. The missing link in these various studies appeared to be a lack of characterization of the starting materials. Without this information, reasons for differences between systems upon environmental exposure were highly speculative.

To unravel the mystery, AMMRC selected the 1009 system, which, although not really in wide use, had a known formulation. This formulation information was important since the characterization effort was still in its infancy. A stable formulation in the starting material was needed to uncover mechanisms of deterioration.

AMMRC exposed samples of cured 1009 at many sites under a variety of conditions, maintaining records on a number of variables. At the same time, laboratory techniques were being developed to follow such characteristics as extent of cure, products of pyrolysis, and effects of moisture. These techniques enabled researchers to follow the complete chemistry of the 1009 system using Fourier transform IR spectroscopy.

One way in which this technique was used was in determining the effect of cure and postcure of the resin. As seen in Figure 1, the graphical display of the change in concentration of the various reactive groups and their reaction products gives an excellent means of describing the cure. This technique was also used in ultraviolet and thermal oxidation studies in the laboratory and in the screening of plates as they were returned from the field. Figures 2 and 3, respectively, show the types of results obtained in these efforts.

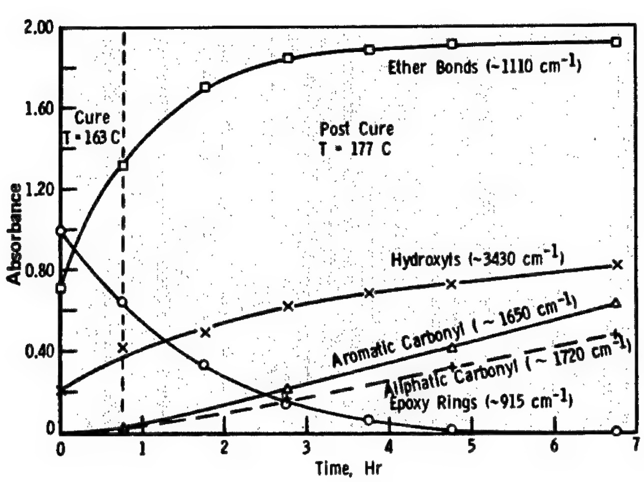


Figure 1

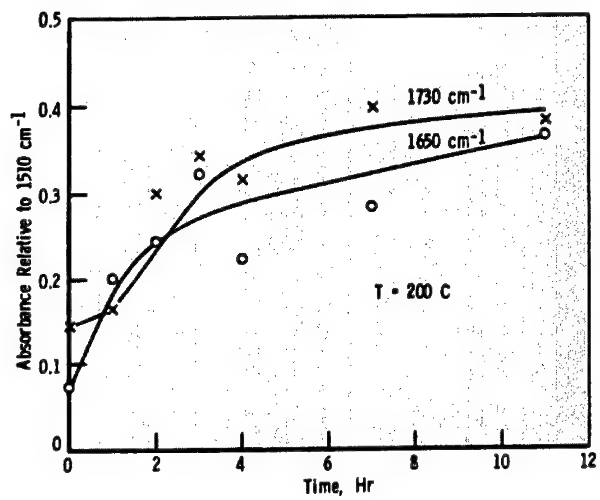


Figure 2

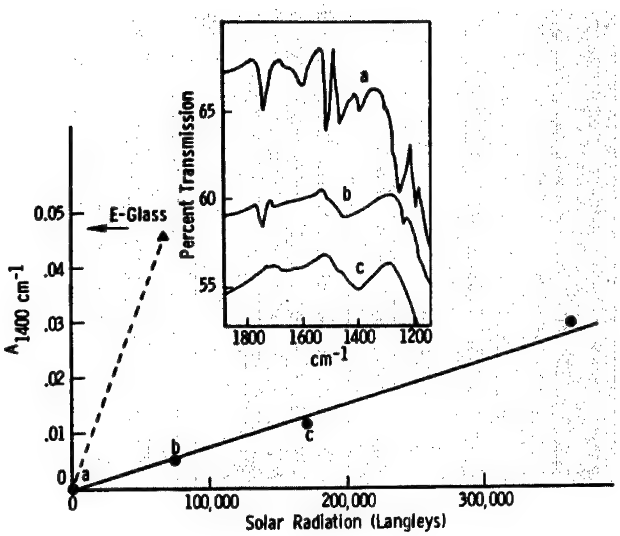


Figure 3

"Fingerprinting" Maintains Control

Meanwhile, high pressure liquid chromatography also was being investigated as a means for monitoring the quality of organic fluids. Combining this capability with the chemical characterization techniques developed on the 1009 system, the characterization of any resin system could be approached with confidence. There was no need to be limited to information supplied by the manufacturer. Efforts then focused on "fingerprinting" the two 250 F cure systems, SP-250 and RAC 7250.

Prepreg materials were purchased at different times and compared with the original buy. Three glasses, E, S-1, and S-2, were also included in the study. Base resins, curing agents, and accelerators for both resin systems were rapidly identified and correlations were drawn between the chromatographic peaks and the spectroscopic traces.

Cure Studies Revealing

Cure studies on the two systems also were conducted. In one case, researchers were able to produce an essentially complete cure, as shown in Figure 4, using the

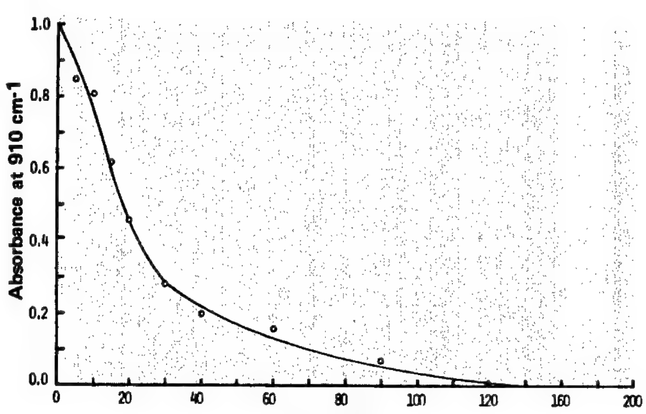


Figure 4

recommended cycle. In the other system, however, the cure was somewhat less than complete (Figure 5). Investigation

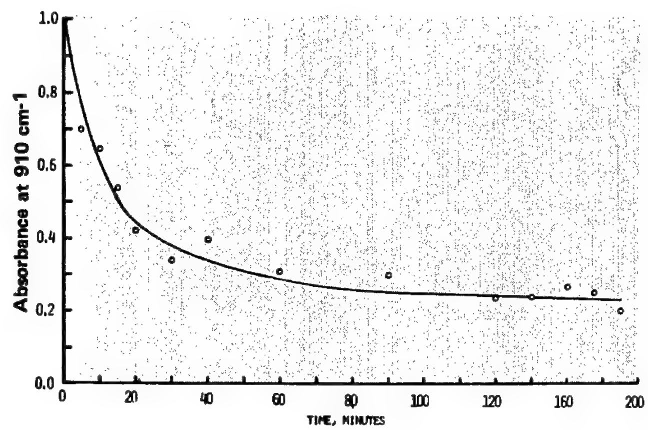


Figure 5

revealed that the problem lay in a process change made by the manufacturer to provide another customer a longer freezer outtime for the material. This change had been initiated before our first purchase of the material, so the difference was not picked up in the chromatographic fingerprinting. The only means for detecting the problem was checking the extent of cure using the spectroscopic technique. But, had the proper baseline material been available, high pressure liquid chromatography would have detected the change more rapidly. This was borne out when a batch of material manufactured prior to the process change was located. This material showed a distinctly different "fingerprint" although the basic constituents of the resin were identical.

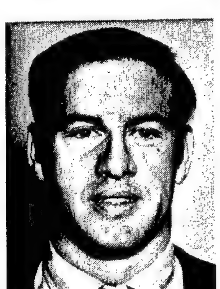
AMMRC also obtained samples of the batch of prepreg that had initiated the customer request for a longer freezer outtime. Both chromatography and spectroscopy indicated distinct differences between this material and AMMRC's initial buy. The important point is that the prepreg had met both the manufacturer's specifications and the customer's requirements on a strictly physical property basis before going bad. The use of either high pressure liquid chromatography or Fourier transform infrared spectroscopy could have detected the problem easily during formulation and allowed cost saving corrective action much earlier in the process.

Graphite/Epoxy Used

Box Beam Structure Filament Wound

P. R. EVANS is Program Manager at Hercules Aerospace on the Army's effort to design half- and full-scale graphite traversing beam prototypes for use in Army mobile bridging. During his ten years of experience in composites, he has directed a program for large filament wound metal lined composite pressure vessels, assisted in the design and fabrication of filament wound NASA Mod O and Mod 1 Wind Blades, and has been instrumental in spar and process design and development for production of AH-1Q composite helicopter blades. He holds B.S. and M.S. degrees in Civil Engineering and a Ph.D. in Structural Engineering from West Virginia University.

JOHN SLEPETZ is a Civil Engineer in the Mechanics of Materials Division of the Mechanics and Engineering Laboratory at the U.S. Army Materials and Mechanics Research Center. For the past ten years he has conducted research in the area of failure behavior of fiber reinforced composites. He has B.S. and M.S. degrees from the University of Virginia and a Ph.D. in Civil Engineering from Duke University. He is a registered professional engineer and a member of the American Institute for Aeronautics and Astronautics.



The use of composite materials promises both cost savings and improved properties in future mobile bridges. Methods and materials for filament winding of graphite/epoxy composite beams have been developed in recent work for the Army Materials and Mechanics Research Center at the Allegheny Ballistics Laboratory of Hercules, Incorporated. Fabrication technology applicable to commercial production was demonstrated during winding of two half-scale beams. Use of the graphite/epoxy composite and filament winding process can provide significant manpower and cost savings over other materials and processes.

Less Weight, More Rigid

The program started with design of a full-scale beam. The fabrication techniques that were demonstrated on half-scale models of this design will be equally applicable to the full-scale beam. This design achieves a 50 pound weight reduction and a 16 percent increase in flexural rigidity over a comparable aluminum design.

The box beam structure is one of three sections of a

launch beam across which a folding bridge will be rolled. The launch beam will be cantilevered during deployment and will function simply as a supported beam. Each section is about 7 meters long. With weight and flexural modulus as its critical design elements, the beam is well suited to the advantages of fibrous composite design and fabrication.

In use, the launch beam sections will require moment resistant joints at both ends. For the demonstration program, a simple box configuration of constant cross section with no end connections was specified to keep tooling and fabrication costs low.

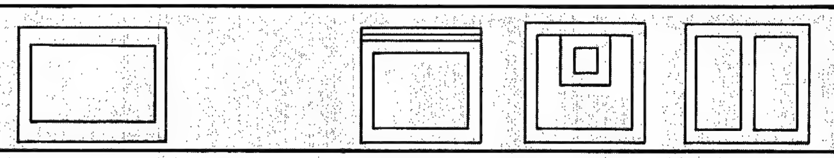
BOX BEAM DESIGN REQUIREMENTS

Element	Requirement
Cross Section Envelope	12.11 in. × 25.00 in.
Length	21 ft, 3 in.
Maximum Weight	20 lb/linear foot
Minimum Bending Moment Capacity	5.52×10^6 in.-lb
Minimum Shear Force Capacity	20,000 lb
Flexural Rigidity	Maximum; greater than comparable aluminum beam
Operating Temperature	-65°F to +165°F
Humidity	98% RH
Fatigue Life	10^4 cycles
Margin of Safety	>0.33 for tension, compression, shear and buckling

Table 1

Several Designs Suitable

Table 1 summarizes design requirements for the full-scale beam. As shown in Table 2, several satisfactory preliminary designs using different configurations and materials were developed. The simple hollow box design using AS graphite/epoxy was selected for development based on technical risk factors and estimated production cost in conjunction with a modified requirement to maximize beam flexural rigidity. The optimum design was considered to provide maximum flexural rigidity within the weight limitation, with all strength margins of safety in excess of 0.33.



	1 Baseline Type As Graphite	2 Type AS Type HM-S Graphite	3 Kevlar-49 Type HM-S Hybrid	4 Type AS/Foam Sandwich Design	5 Type AS/ Stiffener Design	6 Double Box Type AS Design
Flange Thickness (in.)	0.32 @ ±45° AS 0.21 @ 0° AS	0.32 @ ±45° AS 0.21 @ 0° HM-S	0.40 @ ±45° Kevlar 0.18 @ 0° HM-S	0.32 @ ±30° AS 0.18 @ 0° AS 0.25 Foam Sand.	0.32 @ ±30° AS 2"×2"×0.25 Box Stiff @ ±10°	0.32 @ ±30° AS
Web Thickness (in.)	0.32 @ ±45° AS	0.32 @ ±45° AS	0.40 @ ±30° Kevlar	0.32 @± 30° AS	0.32 @ ±30° AS	0.32 @ ±30° AS
Weight (lb/ft)	18.3	18.3	19.9	18.3	17.5	17.5
EI (lb-in.) $(10)^{10}$	2.10	2.47	2.05	2.33	2.22	1.62
Avg. Bending Stress						
Compression Flange (ksi)	31.5	32.0	27.1	24.9	27.0	29.2
Tension Flange (ksi)	31.5	32.0	27.1	37.4	47.3	29.2
Avg. Shear Stress (ksi)	1.2	1.3	1.3	1.7	0.80	1.1
Minimum Margin of Safety	+0.52	+0.77	+0.22	+0.33	+0.33	+0.01
Buckling Stress						
Flange (ksi)	43.4	47.9	36.2	60.0	—	90.0
Web (ksi)	34.9	34.6	4.1[1]	3.8[1]	3.8[1]	34.9
Minimum Margin of Safety						
Flange	+0.40	+0.50	+0.34	+1.40	+6.40[2]	+2.10
Web	+2.64	+3.30	+2.23	+1.25	+3.75	+2.64
Risk	1.00	1.10	1.50	1.50	1.75	1.30
Cost Factors						
Labor	1.00	1.10	0.90	1.20	1.40	1.80
Materials	1.00	1.45	1.73	1.00	0.95	0.95
Tooling	1.00	1.00	1.00	1.00	1.80	1.50
Unit Cost (5000 Units)	$4,040	$5,530	$6,220	$4,220	$4,290	$4,620

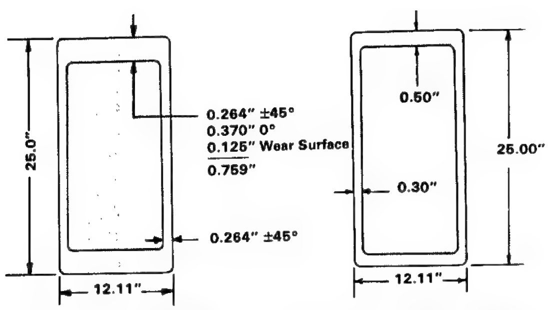
(1) Shear buckling. (2) Based on buckling load.

Table 2

The highest flexural rigidity consistent with weight limitations and beam fabrication considerations is obtained by placing the maximum possible amount of longitudinal (0 degree) fiber in the flanges. The webs consist of diagonally placed (±45 degree) windings which also carry through the flanges. The webs are sized to carry the 20,000 lb shear load and have adequate web or flexural/shear buckling strength. The remaining material allowed by the weight limitation can be placed longitudinally in the flanges. Table 3 compares the resulting final design with a structurally adequate, but overweight, aluminum beam. The composite beam weight was held to 19.1 lb/ft to allow for possibly higher resin content in manufacture and for potential changes in the wearing surface.

Simple Wrapping Technique Effective

In fabricating half-scale beams, prepregged tape was used for the longitudinal portion, allowing employment of the simple, inexpensive fabrication technique shown in



ABL GRAPHITE DESIGN   BASELINE ALUMINUM DESIGN

Item	Program Requirement	ABL Graphite Beam	Baseline Aluminum Beam
Envelope	12.11 ± 1/16 × 25.00 ± 1/16 × 22.9′	Satisfies requirement	Satisfies requirement
Beam Unit Weight	20 lb/ft	19.1 lb/ft(1)	31 lb/ft
Bending Resistance Margin of Safety(2)	0.33	+1.1(3)	+0.1(4)
Beam Shear Load Margin of Safety(5)	0.33	+1.0(6)	—
Flexural Rigidity, EI	Aluminum Beam	$2.89 = 10^{10}$ lb-in.^{2}	2.5×10^{10} lb/in.^{2}

(1) Includes 1.0 lb/ft for 1/8" thick hard rubber or polypropylene wear surface.
(2) Program design ultimate moment is $5.52 = 10^8$ in.-lb.
(3) Minimum margin anywhere in beam flange, shear stress in this instance.
(4) Based on a bending stress of 38 ksi and 6061-T6 aluminum.
(5) Program design ultimate shear is 20,000 lb.
(6) Minimum margin anywhere in the beam web due to the shear load, shear buckling in this case.

Table 3

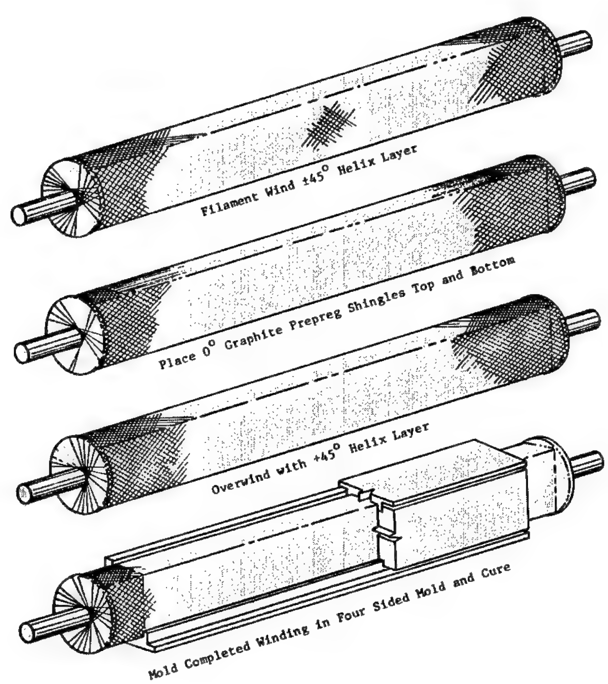


Figure 1

Figure 1. This technique features a winding mandrel and a mold. The beam is built up by alternately wrapping the mandrel with diagonal filament layers and laying continuous prepreg tape longitudinally along the flanges. When the desired beam cross sectional thickness is obtained, the assembly is placed in a simple four sided mold and cured. The mold ensures attainment of the desired external dimensions.

The use of this fabrication technique depends on the availability of a prepreg resin system that is compatible with a usable wet filament winding. A suitable combination is Hercules 1904 graphite epoxy and HRBF-55A winding resin, for use with the Hercules AS-4 graphite filament winding roving. Using this combination, the viscosity of the winding resin decreases during the early curing stages, allowing it to flow freely. This causes resin bleed out and allows mold closure. The prepreg is kept soft and flexible by freezer storage before it is laid in place so that it easily conforms to the mandrel surface under mold

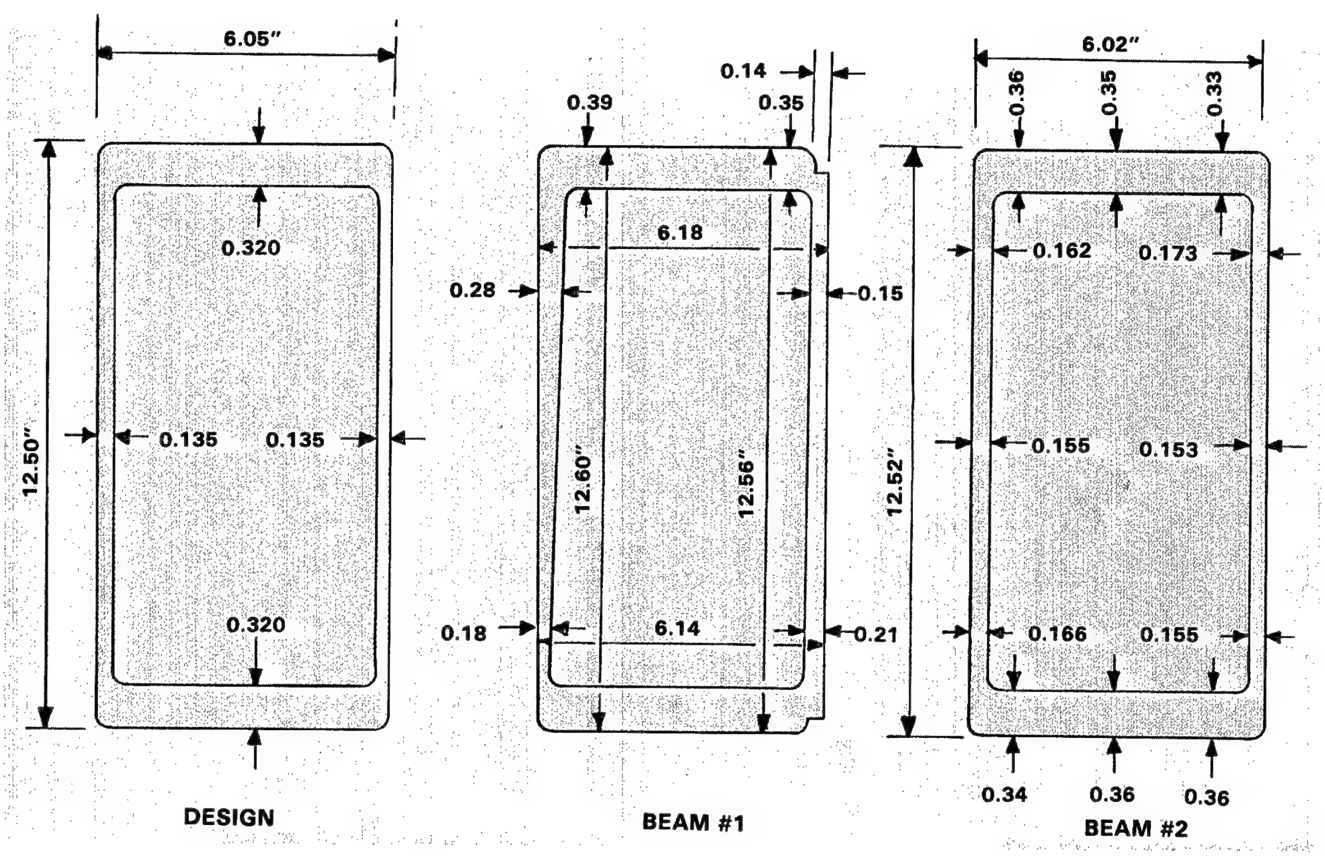


Figure 2

pressure. There is very little flow of the prepreg resin, but it does bond very well to the HRBF-55A. A nicely compacted, strong combination results without unduly critical resin staging.

This was the basic technique used in fabricating the two half-scale beams. The winding mandrel was a glue laminated wooden rectangle with radiused corners. A section of aluminum sheet metal was positioned to provide a sliding surface for mandrel extraction.

In winding, six diagonal helix layers covering the entire mandrel periphery were alternated with five longitudinal prepreg tape shingles placed along the top and bottom of the narrow (or flange) surface. The helix layers were wet wound using a band comprised of six rovings of Hercules AS-4 graphite. This was fed through an epoxy resin filled cup. The longitudinal shingles consisted of seven or eight plies of Hercules 1904 graphite prepreg. These were held in place with hand ties and the overwinding of the next helix layer.

After winding, the assembly was placed in a mold and cured at 120 F for 6 hours and 250 F for 4 hours. With the first beam fabricated, mold closure was poor—the mold plates could not be closed to their bearing surfaces. The resulting beam cross section geometry was not uniform, as shown in Figure 2.

Modifications Improve Product

To enhance mold closure, several corrective steps were taken on the second half-scale beam:

- Winding tension was increased.
- Excess resin was removed after the winding of each helix layer.
- Prepreg mats were consolidated into a single thicker shingle to minimize resin buildup during the helix overwind.
- The mold closing technique was modified so that side plates were nearly close before the top plate was brought in.
- Mold closure bolts were retightened after a 30 minute cure at 120 F while the resin was very fluid and mobile.

With these modifications to the process, a much more satisfactory beam was obtained, as shown in Figure 2. However, both webs and flanges were still a little thick, reflecting a higher resin volume than desired. The finished beam weighed 4.92 lb/ft versus a target weight of 4.80 lb/ft. Further modifications should overcome this problem. Fabrication of full-scale launch beams designed with moment resistant end connections is expected to evolve from the design and fabrication technology advances demonstrated during this effort.

Advanced Composites For Turbines

ALBERT J. WILSON is Manager of Composite Technology Programs for the Aircraft Engine Group of the General Electric Company. He graduated from Northwestern University with a B.S. in Mechanical Engineering and subsequently received a Master's Degree in Business Administration from Xavier University. He has considerable background in the application of advanced technology to power systems. This background includes application engineering of the roll formed cases for the first stage solid propellant rocket motor of Minuteman and management of nuclear alkali metal Rankine cycle powerplant programs for NASA. His aircraft engine background includes supervision of engine assembly and test, marketing, and program management. Most recently he has been manager of technology programs involving composite fan and compressor blade development, composite fan frame producibility, and high temperature composite duct and frame development.

G.E. Projects Large Savings

With savings of more than $10,000 per engine already demonstrated on current aircraft, General Electric is actively seeking other ways to employ composite materials in engine design. Glass/epoxy composites have proven themselves and the emphasis has shifted to advanced composites. Much of G.E.'s current effort is through service sponsored ManTech programs, for which the potential payoffs are very high. And that's only one of several applications under investigation.

Glass/Epoxy Proven in Service

The savings potential and serviceability of glass/epoxy engine parts is well proven—G.E. engines with composite components have now logged more than twelve million hours of flight time. Composite application to large engines began with the TF39 engine. Introduced in 1968, this engine powers the Air Force C5A transport. By replacing metal parts on the TF39 with composites, G.E. reduced its weight by 100 pounds and saved about $10,000 per engine.

The TF39 evolved into the CF6 family of commercial engines which were introduced in 1971. These engines are used on the McDonnell/Douglas DC-10, the Airbus Industries C300, and the Boeing 747 and 767 aircraft. Figure 1 shows the composites now used in the CF6 engines. The general use to date has been in low stress, low temperature applications where glass/epoxy has been shown to provide excellent life while requiring minimal maintenance. The CF6 engines weigh 160 pounds less than they would with metal components and cost $13,000 less.

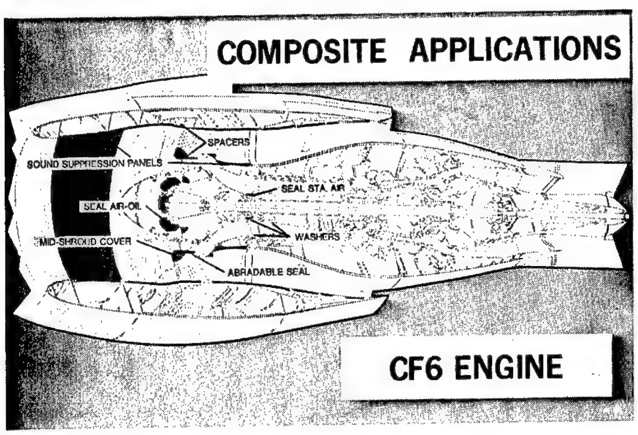


Figure 1

The savings on these engines are real—proven over a number of years of production—and not simply projections. Based on favorable experience with them, G.E. is seeking new engine applications for advanced composites. They are now concentrating on stress and temperature levels beyond the capabilities of glass/epoxy.

A first step in this direction was a program for NASA-Lewis Research Center. In the Quiet Clean Short Haul Experimental Engine (QCSEE) program for NASA, G.E.'s Advanced Engineering and Technology Programs Department demonstrated the value of advanced composites. Ultimately, they were able to construct an engine in which these materials comprise over 30 percent of its weight. Figure 2 shows the areas where composites were used and Table 1 lists the composite combinations utilized in each component. Three of these components—the fan frame, the inner duct, and the fan blades—are of particular interest.

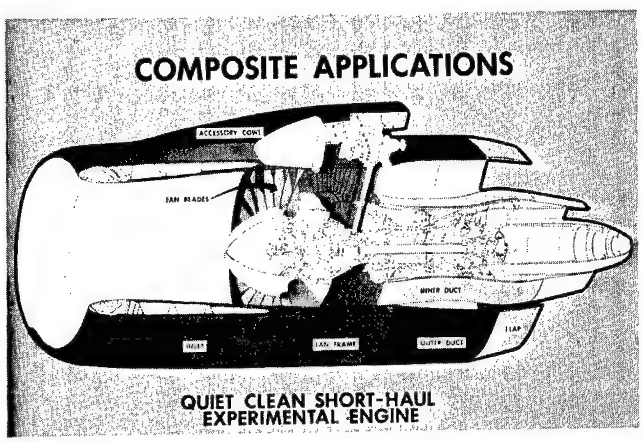


Figure 2

Part	Composition
Inlet	Kevlar Fabric/Epoxy with Aluminum Honeycomb
Fan Frame	Graphite (Type AS, Unidirectional Tape)/Epoxy
Outer Duct	Graphite Type AS, Unidirectional Tape)/Epoxy—Inside Kevlar Fabric/Epoxy—Outside
Flaps	Graphite (Type AS, Unidirectional Tape)/Epoxy—Inside Kevlar Fabric/Epoxy—Outside
Inner Duct	Graphite (T-300, Fabric)/Polyimide (PMR-15)
Blades	Graphite (Type AS, Unidirectional Tape) with S-Glass, Kevlar Fabric, Boron/Epoxy

Table 1

20% Plus Weight Savings

The **fan frame** shown in Figure 3 supports the core engine weight and is built entirely of graphite/epoxy. It is by far the largest, most complex engine component yet fabricated from advanced composite materials. Designed for a maximum stress level of over 100,000 psi, the frame can survive the unbalance forces resulting from loss of five fan blades at one time. In a flight type engine, it would weigh only 474 pounds—about 20 percent less than an equivalent metal frame.

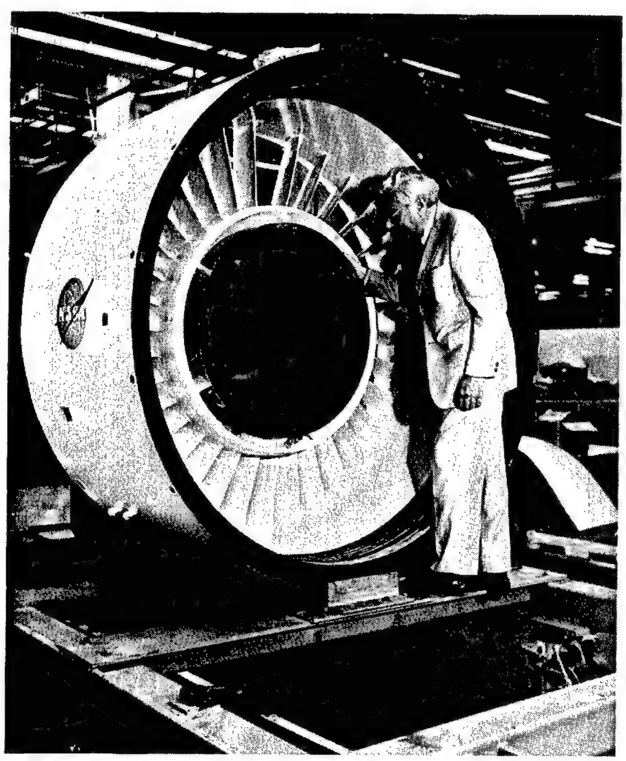


Figure 3

The **inner duct** shown in Figure 4 is made from graphite/polyimide (the NASA-Lewis Research Center developed PMR-15 resin) to withstand temperatures of over 500 F. It is the largest engine component built to date from graphite/PMR. This is a very complex part, requiring acoustic treatment as well as hinges and hardware for attachment to the engine support pylon. Duct skins are processed in an autoclave at 525 F and 100 psi with a postcure at 600 F. The experimental duct has been exposed to engine operation at temperatures exceeding 500 F with no deleterious effects.

The QCSEE **fan blade** design is unique. The blades are made of graphite/epoxy, kevlar fabric, glass, and boron fibers, with additional features as shown in Figure 5. The blades must rotate 180 degrees during engine operation to provide reverse thrust. Composite fan blades such as these

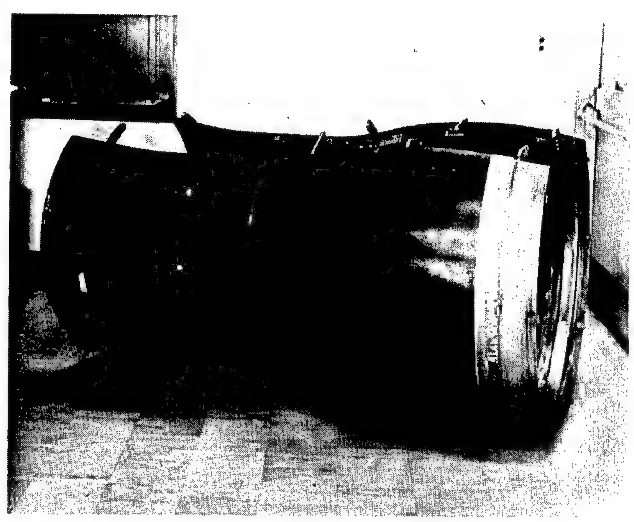


Figure 4

and blades made with other polymeric and metal matrix combinations meet both engine stress and aerodynamic performance requirements. The primary difficulty to date has been in developing sufficient resistance to damage from objects such as birds.

QCSEE UTW COMPOSITE FAN BLADE AND PLATFORM

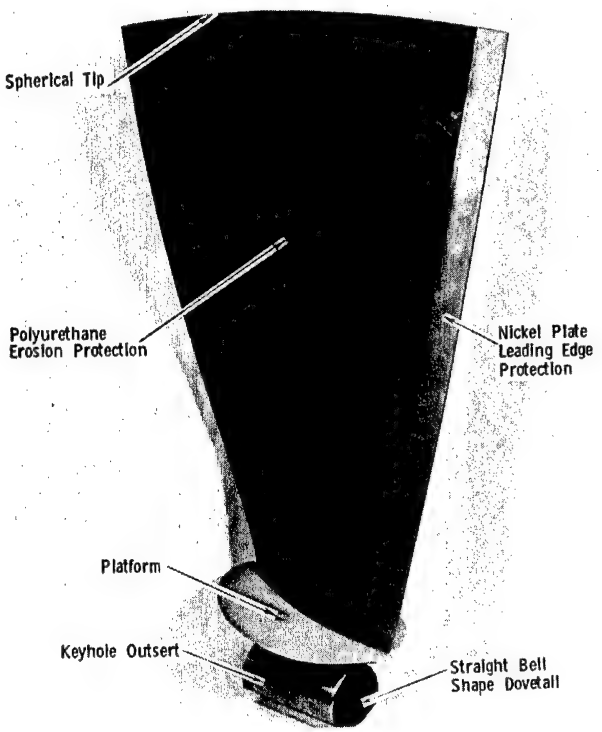


Figure 5

Engine Tests Promising

The QCSEE engine is shown in Figure 6. It has completed 150 hours of operation at the General Electric Peeble Test Site near Evendale, Ohio, and has been installed for additional testing at the NASA-Lewis Research Center. The composite frame and duct have met all expectations and have instilled added confidence in the application of advanced composites to production engines.

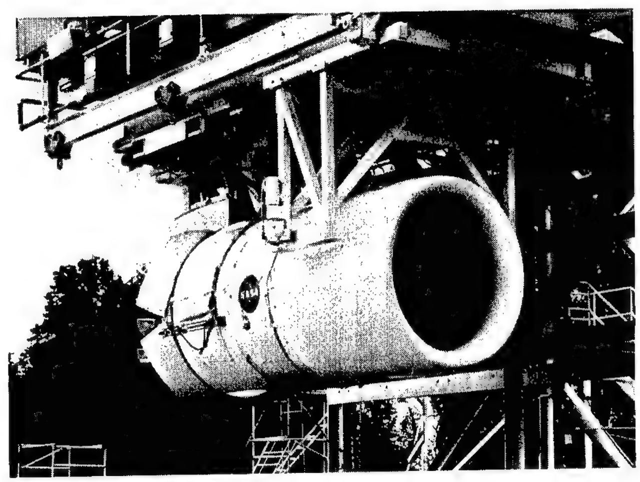


Figure 6

The QCSEE program proved the feasibility of building major engine components from advanced composites. However, the ability to build them in a cost effective manner remained to be demonstrated. With an ongoing Air Force program and anticipated Navy and Army ManTech support, G.E. is now looking at this aspect of development.

ManTech Effort Under Way

In one such effort, the Air Force Materials Laboratory is sponsoring a program to demonstrate the cost benefits of an advanced composite fan frame. The effort was launched in September, 1978, with Rohr Industries as the major subcontractor. The fan frame chosen for investigation is for the TF34 engine (A-10 aircraft). This complex part already is a sophisticated multimetallic/fiberglass assembly, as shown in Figure 7. However, advanced composites still offer attractive potential weight and cost benefits. The experi-

mental composite fan frame shown in Figure 8 is designed to incorporate all of the functions of the metal frame, permitting direct substitution. Its use should reduce weight of the frame by more than 40 pounds—a 23 percent reduction.

G.E. will build four TF34 composite fan frames in a production shop using production techniques. By carefully monitoring and documenting costs, they will project the composite frame cost out to the 250th unit where a direct cost comparison with the 250th production metal frame can be made.

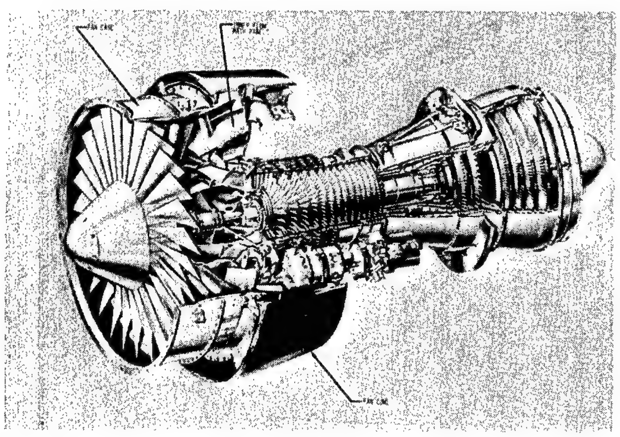


Figure 7

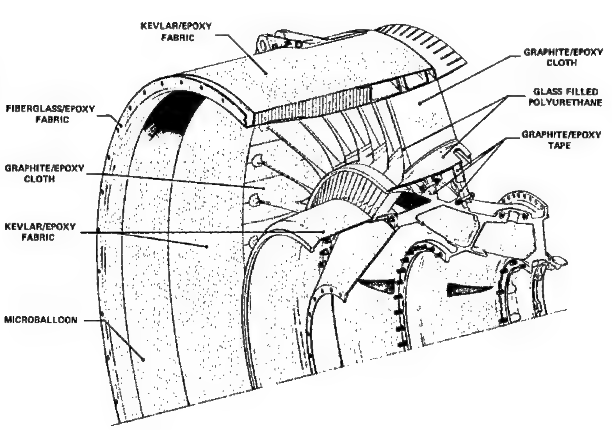


Figure 8

Multimillion Dollar Savings Potential

In another program, NAVAIR is evaluating graphite/PMR-15 composite to replace the present chemically milled titanium used for the duct on the F404 engine (Figure 9). This engine is used on the F-18 aircraft. G.E. estimates a 10 pound (22 percent) weight reduction per duct and an equivalent cost savings compared to the titanium part. NAVAIR R&D funding is now being applied to supplement NASA-Lewis funds for process refinement work of the graphite/PMR-15 system. This will pave the way for subsequent Navy ManTech activity. Once again, the ManTech program would support a short production run with cost monitoring and projection to the 250th unit. Successful static and dynamic testing would be followed by engine and flight testing. The composite duct could be part of F404 engine production in 1982.

Finally, the Army has shown interest in applying advanced composites to the inlet particle separator of the GE T700 engine shown in Figure 10. This engine is used on the UH-60A and YH-64 helicopters. This component is especially challenging because of the high pressures and high temperatures of the anti-icing air under certain engine operating modes.

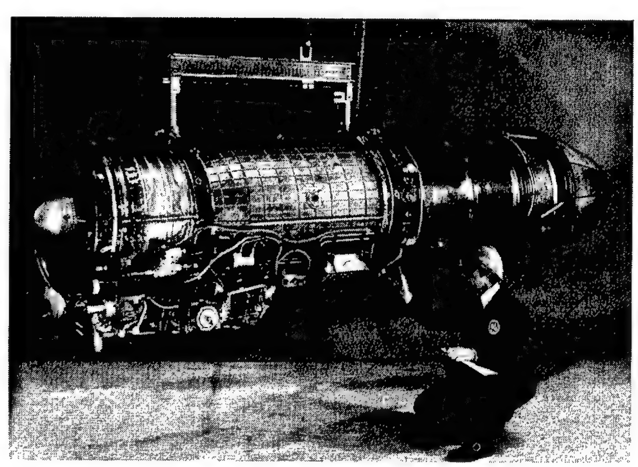


Figure 9

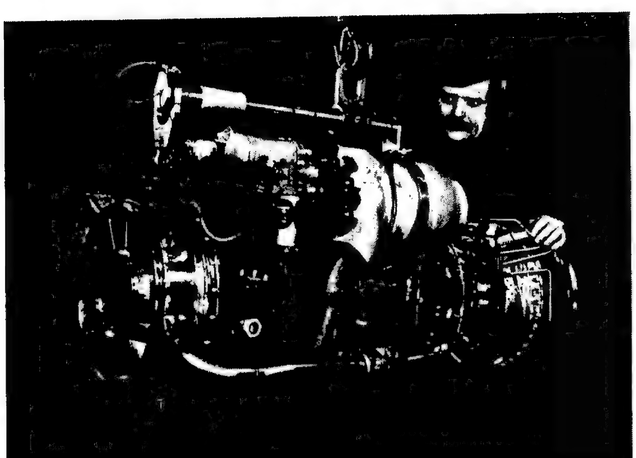


Figure 10

General Electric plans to apply advanced high temperature composite fabrication techniques to produce the particle separator. The final design concept will require the combination of composite and metal components in such a way as to take maximum advantage of the material properties of each. Sheet steel will be used for surfaces requiring erosion protection and anti-icing. Unidirectional graphite layups and hoop wound reinforcements will be incorporated to handle the high pressures. Polyimide resin such as PMR-15 will be used to withstand the 530 F maximum temperature condition. Despite this complex combination, the Army ManTech program is expected to result in impressive cost and weight reductions compared to the all metal design of the present particle separator.

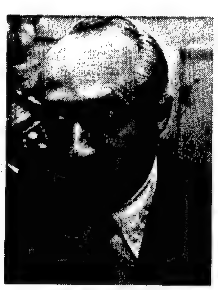
These ManTech programs of the Air Force, Navy, and Army will be of prime importance in bringing advanced composite components into production readiness. Each of the components described has generic value in that all aircraft engines have frames and ducts. The success of these ManTech programs will stimulate additional interest at General Electric and at other manufacturers to promote the use of advanced composite applications in aircraft gas turbine engines.

Service Life Increased

Composite Rotors—An Evolving Art

Current development work on helicopter blades made from composite materials indicates that significant reductions in production costs and improved blade performance are on the way. It's all part of an evolving process of improved composite blade technology that is bringing increased composite blade use. The growth in use is a result of demonstrated improvements in aerodynamic performance, reliability, and service life. Judging from current manufacturing technology programs to improve materials and design and also to reduce production costs, this growth rate should accelerate in the future.

Composites have become increasingly attractive because of the poor durability and high life cycle costs of current metal blades demonstrated by a growing body of data. Metal blades are sensitive to routine service incurred nicks and scratches that can lead to fatigue failure. They are also susceptible to corrosion and concealed deterioration. All of this adds up to a very high early retirement rate. Since metal blades are not easily repaired, their full utilization often is quite low. Composite rotor blades can provide significant improvement in all of these areas of service life, and they are readily and easily shaped to optimum aerodynamic configurations.



PAUL F. MALONEY is Director of Engineering for Kaman Aerospace Corporation, where he is responsible for engineering design, stress analysis, and materials engineering as applied to new products. He received a B.S. from the University of Buffalo in 1951 and an M.S. in Mechanical Engineering from Rensselaer Polytechnic Institute in 1960. His twenty-eight years of rotary wing experience include responsibility for the design, structural analysis, and fatigue substantiation of rotor blades. He also acted as principal investigator on a large number of R&D contracts in his area of specialization involving unique new rotor concepts and materials applications that contributed to improved producibility. Prior to his present assignment, Mr. Maloney served as Program Manager for the development of the Improved Main Rotor Blade for the Army's AH-1 Cobra Helicopter.

All of these technical advantages wouldn't be enough, however, unless the blades could be produced at a competitive cost. Improved manufacturing technology was, and continues to be, a key to the successful implementation of composite rotor blade technology. Let's consider the evolution of that technology—its roots, where it stands now, and where it seems to be going.

The Roots of Composite Blade Technology

Various kinds of wood provided the main structural elements in early rotor blades. Then in the early 1950's bonded metal blades were developed with varying degrees of success. From these beginnings, a substantial increase in power and gross weight was provided for in the Air Force HH-43B helicopter, which was developed by Kaman from earlier synchropter models. All critical sections of this basically wooden blade contained significant fiberglass reinforcements.

Primary reinforcement in the HH-43B blade was through glass fibers embedded in an epoxy matrix. These fibers were applied manually both by wet layup and in the form of preimpregnated tape at the various blade sections. Approximately 2,000 of these blades were manufactured, eventually logging about two million flight hours with no major service problems.

As a result of this successful experience, Kaman proceeded to develop an all fiberglass main rotor blade for the HH-43B under company funding. The first flight using this blade shown installed on the HH-43B in Figure 1 was in January 1961. These rotor blades were hand made by wet layup of dry fiberglass cloth and epoxy resins. Their projected production cost was somewhat less than that of the wood core blades. However, because

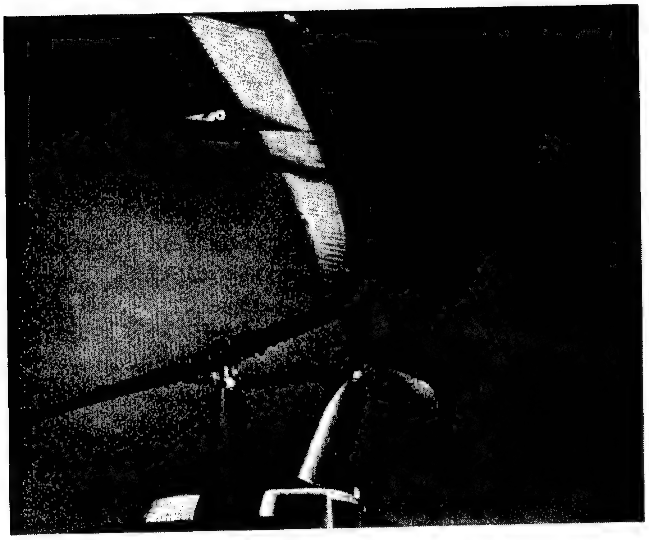


Figure 1

those wood core blades were experiencing success in service, this early fiberglass blade was never fully developed.

Fiberglass Skins Prove Successful

During this same period, Kaman developed and produced the UH-2 helicopter for the Navy. This was a utility helicopter designed to operate from the decks of aircraft carriers and smaller vessels. Its rotor blades had extruded aluminum spars and preimpregnated fiberglass skins that were precured and bonded over aluminum honeycomb core.

Questions were raised concerning the long-term durability and resistance of this skin and core combination in a corrosive marine environment. However, the UH-2 helicopter has since been developed into the SH-2F LAMPS helicopter, which is successfully operating off small surface vessels using the blade. Furthermore, UH-2 blade components with as high as 1700 hours of service showed no degradation of the fiberglass skins and no corrosion of the aluminum core in destructive engineering tests. Approximately 1700 of these blades have been built and have accumulated more than two million hours of service.

Other Applications

Kaman engineers have employed fiberglass in other rotor blade applications. The Elastic Pitch Beam Tail Rotor shown in Figure 2 was developed under Army contract and flight tested on a UH-1H helicopter. It was designed as a direct replacement for the existing all-metal tail rotor, employing fiberglass for several important functions.

The fiberglass blade retention strap (Elastic Pitch Beam) is a monolithic structural element running from one blade through the hub area out into another blade. It provides basic centrifugal reaction of one blade against the other, meanwhile permitting the necessary pitch change through elastic torsional deformation. This can be achieved because of the anisotropic properties inherent in unidirectional composite materials. The fiberglass provides high axial and bending strength in a member that has sufficiently low torsional stiffness to permit pitch change without undue directional control loads.

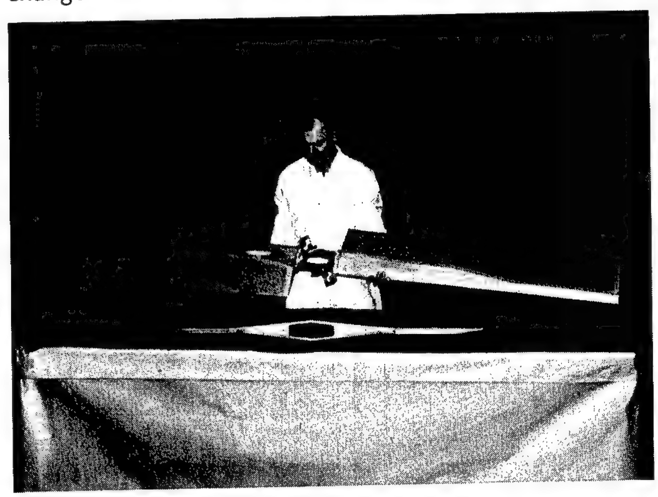


Figure 2

The aft structure of this rotor blade uses fiberglass skins over Nomex core to close out the airfoil. The concept was thoroughly developed and flight tested for a total of sixty hours in the course of the Army sponsored program. The success of the concept is best demonstrated by the fact that it is now employed in the UTTAS helicopter.

Reduced Costs Are Demonstrated

To further extend the potential of fiberglass composite structures, Kaman conducted a program to demonstrate reduced rotor blade acquisition and operational costs. Low cost materials and unique repair techniques were applied to the main rotor blade, shown mounted on a whirl test stand in Figure 3. The level of

field repairability achieved on this blade was higher than was possible with then current metal blades. Many studies and analyses demonstrated that this degree of repairability would greatly reduce premature blade removal and extend blade operating time appreciably beyond that experienced with metal blades in service. The basic concept is now an inherent part of the AH-1 improved main rotor blade system being delivered to Army operating units.

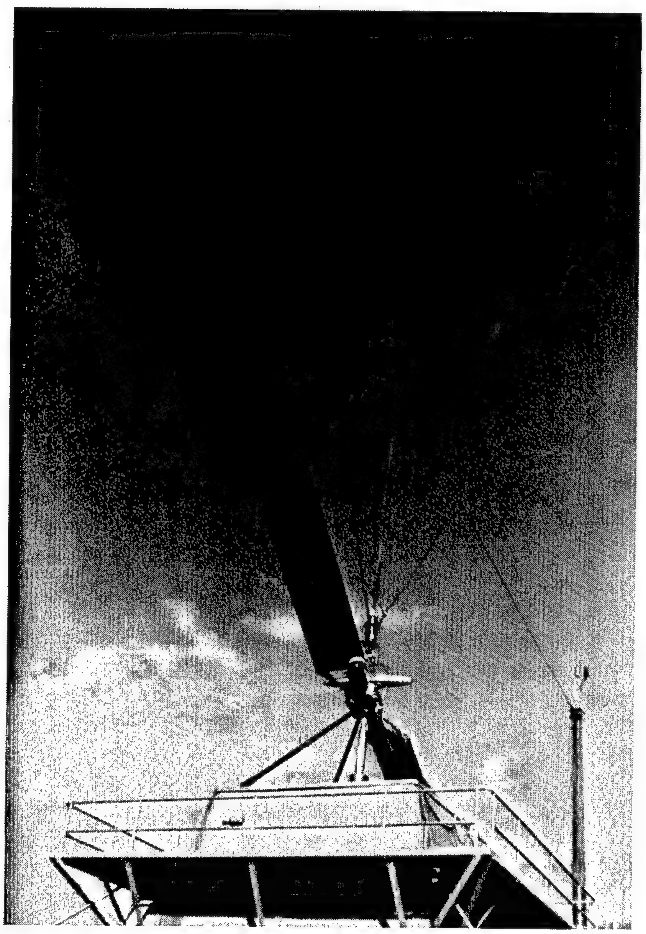


Figure 3

Where Do We Stand In Composite Blade Technology?

The composite main rotor blade now in a low rate initial production phase for the AH-1 represents the current state of the art in automated blade fabrication. This blade, shown mounted on the Cobra helicopter in Figure 4, provides Army operating units with an improved level of performance, greater survivability, reduced detectability,

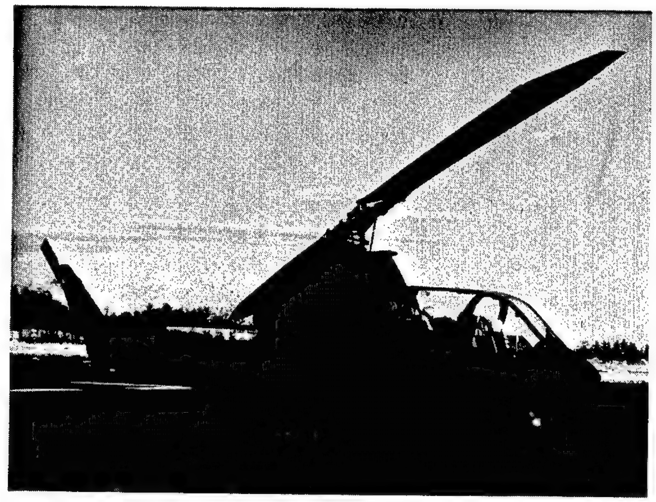


Figure 4

and improved reliability and maintainability. Accompanying these improvements are low production and service costs. Service costs are less because the blades have a high level of damage tolerance and repairability. The improved blade results from fresh conceptual approaches both to design of the blade and to its manufacturing technology.

The blade structure is shown in Figure 5. Its major elements are formed by wet filament winding. The main spar, the trailing edge spline, and the rotor blade skins all are formed on specially designed automated equipment. The result is a consistent, reproducible blade of high integrity produced in a minimum number of man-hours.

The spar and skins utilize S-glass as the reinforcing fiber. The trailing edge element uses organic Kevlar fibers. All of the fibers are embedded in an epoxy matrix. The basic materials of the rotor blade are bought in their elemental form—dry fibers on a spool and epoxy resins and hardeners in drums.

Costly Processing Eliminated

In production, a single mechanically controlled process brings the fibers and resins together and properly

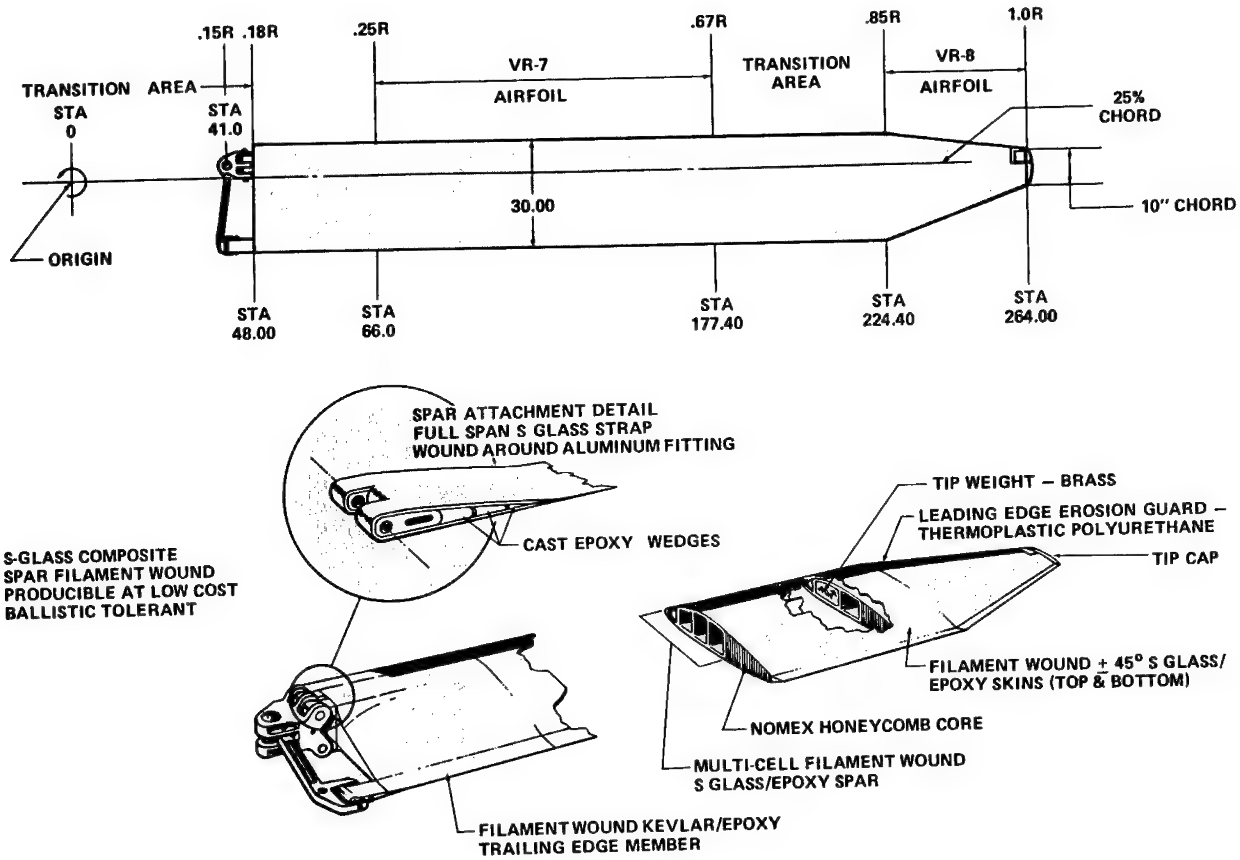


Figure 5

locates and orients them. The costly intermediate processing needed with preimpregnation of tape or roving is eliminated. The process provides precise positioning of fibers with good straightness and controllable tensioning.

After filament winding, the spar and trailing edge spline are cured and the major blade assembly bonded in hard matched metal molds. This process insures a high degree of bond integrity and a consistent, reproducible airfoil shape. This development program has aptly demonstrated the capabilities and advantages of composite blades.

Where is Composite Blade Technology Going?

Predicting trends in this rapidly changing composite technology can be a risky business. However, we can expect future materials and processes to spring from the research and development being conducted today. The continuing goal is to minimize production costs while providing significant technical advantages.

Production processes must be geared to handling airfoil and planform changes over the length of the blade. As much as possible, this will have to be done on automated equipment to reduce labor costs and manufacturing line losses that are due to human error. Such equipment will have to be capable of laying up a large amount of composite in a short time—and in a precise, controlled fashion.

Current Programs Indicate Future Trends

Contributions to future production technology should come from the Circulation Control Rotor (CCR) under development for the Navy and a large wind turbine blade under development for NASA and DOE, as well as

ongoing Army ManTech programs in composite rotor fabrication.

A cross section of the CCR blade is shown in Figure 6. In this unique rotor concept, tangential blowing of air through a thin slot near the trailing edge of the blade provides the effective pitch change required. Design constraints on this rotor virtually dictated the use of composite materials to achieve the necessary strength, stiffness, and geometric variations.

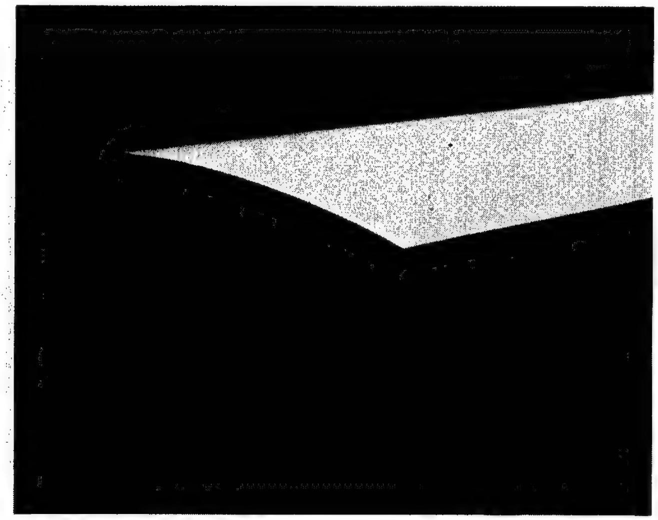


Figure 6

The blade uses a hybrid composite of graphite and fiberglass. Because relatively few of these blades are presently required, it is fabricated by layup of preimpregnated tapes on an inflatable mandrel. The blade is expanded inside hard matched metal molds during the cure cycle to obtain an excellent aerodynamic contour. This process minimizes post cure cleanup and handling while maximizing the aerodynamic fidelity of the blade.

Rapid Layup Developed For Large Blade

Figure 7 shows the composite wind turbine blade now under construction for NASA and DOE. This blade is designed for a 300 foot diameter windmill. The blade spar is formed from a unique material called Transverse Filament Tape on a machine especially designed to lay up large amounts of fiberglass in a unit time. The material contains a very high percentage of fibers oriented at right angles to the tape length. Therefore, with wide tapes, large amounts of 0° fiber can be applied to a rotating mandrel in a short time. Experience to date with this advanced material and process indicates that the complete 20,000 pound fiberglass spar can be wound in an 8 to 10 hour shift.

Braiding A Fast Technique

Braiding is another promising method of high rate layup for composite materials. Development of this process for advanced composite fabrication has been under way for some time and its application to helicopter blade spars seems natural. Using current braiding equipment, the number of rovings applied at one time could be increased tenfold. With further development of the process, even greater increases are possible.

When results of this current development work are implemented on future generations of composites blades, it is clear that significant reductions in production costs and improvements in blade performance are foreseeable in the very near future.

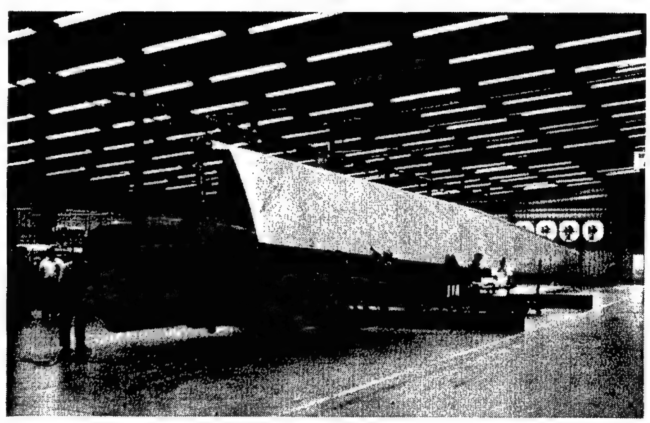


Figure 7

Metal Matrix Stiffener

Composites for Noise Reduction

Continuing work at Boeing-Vertol indicates that FP* aluminum fibers in a magnesium matrix are effective in stiffening helicopter main transmission housings. This stiffening is desirable to reduce vibration, noise, and deflection in the transmission. Noise reduction in both military and civilian helicopters is currently a major R&D interest, with transmissions being one of three major noise sources (along with rotor blades and engines).

Vacuum Metal Infiltration Used

Boeing-Vertol has achieved good manufacturing quality in representative cast magnesium shapes reinforced with Fiber FP. They have demonstrated the manufacturing technology necessary to fabricate a complex metal matrix structure using this combination, as well as procedures for developing Fiber FP preforms. This development includes the use of vacuum metal techniques for infiltrating the preforms with metal.

However, considerable effort still is needed before development of a production Fiber FP/magnesium composite transmission housing is realized. In this regard, Boeing-Vertol recommends

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Figure 1

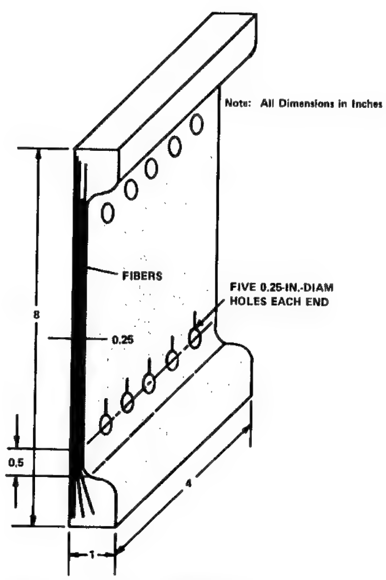
- Compilation of an adequate data bank on the properties of these composites
- Investigation of a monolithic investment casting technology for large, complex structures using continuous one piece fiber preforms
- Development of ceramic shell casting techniques to replace the present metallic expendable tooling.

Fiber FP is an experimental, continuous aluminum oxide fiber under development by DuPont. It is essentially 100 percent polycrystalline alpha alumina of purity greater than 99 percent Al_2O_3 and fired to a density of 98 percent of theoretical. It is inherently stable at elevated temperatures and is compatible with a variety of metal systems. The projected cost of Fiber FP is competitive with graphite and substantially below that of large diameter monofilaments of boron and silicon carbide.

Gear Housing Selected

Work at Boeing-Vertol has been directed to the bevel gear housing of the forward transmission. The purpose is to assess the potential applicability of metal matrix composite materials for the selective stiffening of a transmission housing. Several basic shapes representing typical cross section elements of the housing were fabricated with Fiber FP in a magnesium matrix.

A model of the simulated housing specimen is shown in Figure 1. The three major areas of this housing represented in test specimens were the outer shell cross section (Figure 2), the outer rim/web/inner rim cross section (Figure 3), and the outer rim/web/inner rim components represented by cylindrical shapes (Figure 4).



SPECIMEN CONFIGURATION	DRAWING	FIBER ORIENTATION AND VOLUME, %	MATERIAL
OUTER RIM CROSS SECTION, FIBER REINFORCED	SK27376-1	60°–0°–60° 65	FIBER – DU PONT FP, 20-MICRON NOMINAL DIAMETER, 200-KSI UTS MINIMUM MATRIX – MAGNESIUM ALLOY
OUTER RIM CROSS SECTION (BASELINE SPECIMEN)	SAME AS SK27376-1 EXCEPT NO FIBERS SK27376-2	NONE	AZ91C MAGNESIUM ALLOY

Figure 2

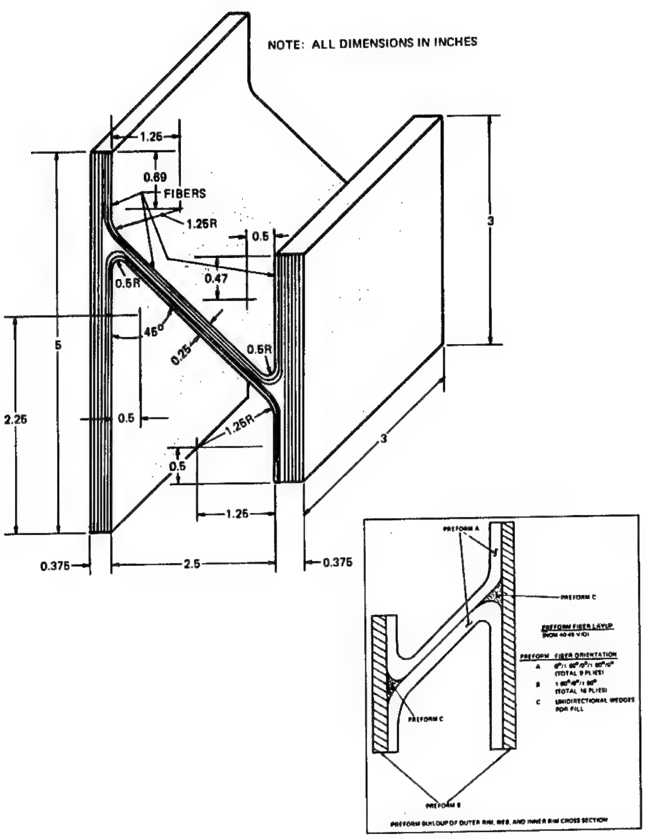


Figure 3

Specimens were fabricated using a DuPont developed casting process based on liquid metal infiltration. Figure 5 is a flow chart showing the process used to prepare FP/magnesium castings. In the final step, there are numerous methods for infiltrating the metal into the Fiber FP preform assembly. However, the best castings in terms of soundness and mechanical properties have been obtained by preevacuating and preheating the mold assembly before introducing molten metal.

Vacuum Technique Complex

Figure 6 illustrates the steps in fabricating a thin wall tube by liquid metal infiltration with metal molds. Initially, the Fiber FP sheet material is modified by adding an ash free organic binder to improve flexibility and adhesive tack. The sheets then are cut into tape, laid up into the desired ply pattern, and preshaped to fit the test specimen shape using moderate heat and pressure (Step 3). For a simple shape, such as the cylinder shown here, the completed preform is then installed into the outer shell of the casting mold.

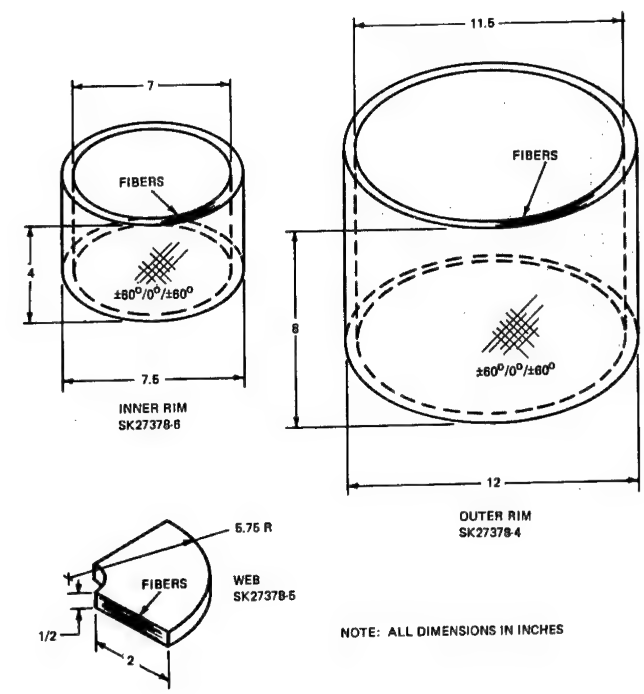


Figure 4

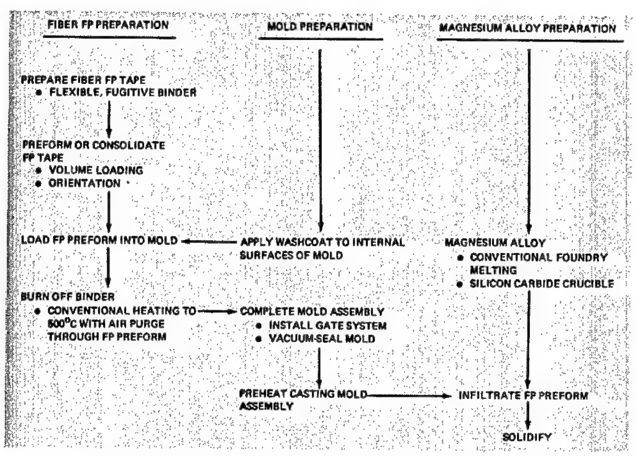


Figure 5

A vacuum bag is installed and the preform is compacted and adhesively tacked together. The preform may then be stored or moved directly to the casting area. At the casting area, the preform is inserted into the casting mold (Step 8), the binder is burned out (Step 9), and casting is completed (Step 10). The mold is removed after cooling and the specimen is now complete except for removal of excess material.

The preform for the outer rim/web/inner rim cross section was the most complex shape developed in this program. Figure 7 shows the various steps in preparing this preform, which was comprised of six individual preforms.

Figure 8 is a schematic diagram of the molten metal infiltration process used to fabricate the test specimens. The casting mold must provide an adequate gating system and riser to prevent fiber damage or distortion during casting. Either remote or immersion filling was used, depending upon the type of specimen to be cast. In remote filling, the uppor portions of the mold are in-

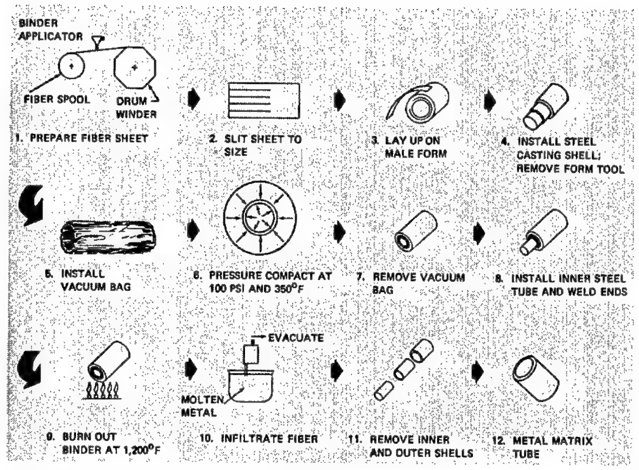
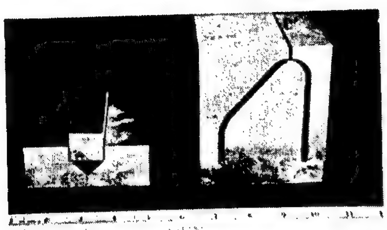


Figure 6

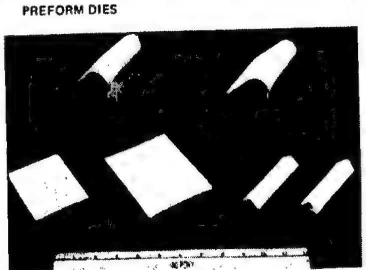
sulated with a refractory fiber blanket. This keeps the casting area at molten metal temperature while the gate and inlet tube areas are immersed in the molten filler metal. This technique is the most practical for larger, more complex shapes. In immersion filling, the entire mold is immersed within the molten metal bath after the fiber burnout is complete.

Diamond Tools Required

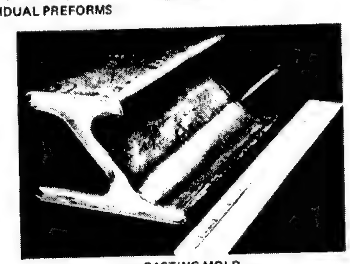
During production, some cutting, machining, and drilling will be required to finish the near net shape parts that are cast. The Fiber FP is hard, with a high modulus and abrasive characteristics. Thus, diamond edge tools and cutting and machining methods developed for boron fiber reinforced composites will probably be required. On experimental specimens, carbide tipped twist drills were used for drilling, with acceptable hole finish. Carbide tipped tools were also used for lathe turn machining with excellent results.



PREFORM DIES



INDIVIDUAL PREFORMS



CASTING MOLD

Figure 7

Secondary joining of components will also be necessary in production and Boeing-Vertol has directed some effort toward welding techniques. Initial attempts showed that deep penetration welds made by electron beam or laser welding were not practical. Aluminum-zinc soldering and metal inert gas welding with a magnesium wire did produce suitable fillet joints. However, with all methods used there was no metallurgical joining in areas where fiber ends were exposed. Partial success in these areas was achieved when specimens were coated with aluminum by plasma arc metal spraying. The joining experiments showed that welding is feasible, although further development is necessary. When tested, the cast specimens exhibited acceptable mechanical properties that correlated well with results predicted analytically using a finite element model.

Results of this program offer considerable encouragement for the full-scale development, fabrication, and evaluation of metal matrix composite helicopter main transmission housings.

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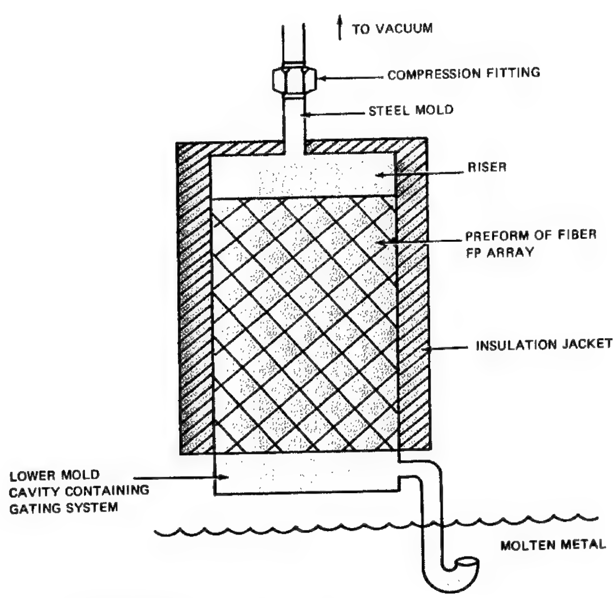
* FP Fiber is a trademark of E.I. duPont Co.



CASTING SEQUENCE

- PREHEATING OF MOLD (STEP 9, FIGURE 24)
- CASTING/INFILTRATION OF MOLTEN METAL (STEP 10, FIGURE 24)
- PROGRESSIVE SOLIDIFICATION

Figure 8

Improved Survivability

Fiberglass Flight Controls

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Protection of flight control systems from small arms fire is of major importance to the survivability of helicopters in combat—in Vietnam approximately 35 percent of the helicopter losses resulted from ballistic damage to flight control components. These parts are generally forged or cast from notch sensitive metallics and are designed to minimum dimensions to save space and weight. Any means to reduce their vulnerability could sharply reduce helicopter losses in any future combat operations and provide very significant materiel savings. If flight control system manufacturing costs could be reduced at the same time, the ultimate savings would be even greater.

Thus, the design of flight control systems is a major consideration in developing the next generation of Army helicopters. One of three approaches under careful consideration is the use of composites for "ballistic damage tolerant" flight control components. The other two approaches are the use of redundant metallic components (if one system is knocked out a duplicate is immediately available) and fly by wire control systems.

Composites Provide Damage Tolerance

In the ballistic damage tolerance concept, system components are designed specifically to accept ballistic penetration—even in the most critical areas—while remaining functional. Composites are one way of achieving this. Several programs at the U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL) have demonstrated the feasibility of making ballistic damage tolerant control system components from composite materials. More recent work has demonstrated manufacturing technology for turning out such components on a production basis. The need was for low cost techniques that would provide high producibility. The results of several programs indicate that quality parts with satisfactory performance can be produced at high rates. Furthermore, projected manufacturing costs are generally considerably less than those of current metal components.

In one of these demonstration efforts, Whittaker Corporation developed manufacturing methods and

technology for glass reinforced plastic components using low cost fabrication techniques. The component sets produced included a connecting link, an idler arm, and two bellcranks for a typical helicopter flight control system.

Large Savings In Production Costs

The projected cost of manufacturing the connecting link on the basis of 1000 units was only about one eighth that for the current metal part. Projected costs of the forward bellcrank and the idler arm were reduced approximately 50 percent and cost of the second bellcrank by about 25 percent.

Designs of the four components investigated by Whittaker are shown in Figures 1 to 4. They were fabricated primarily from chopped glass epoxy bulk molding compound (BMC) and NEMA G-11 FR grade flat sheet and tubular shapes. The first step in the development was redesign, with three of the four components (all but the connecting link) greatly simplified from the standpoints of both design and manufacturing.

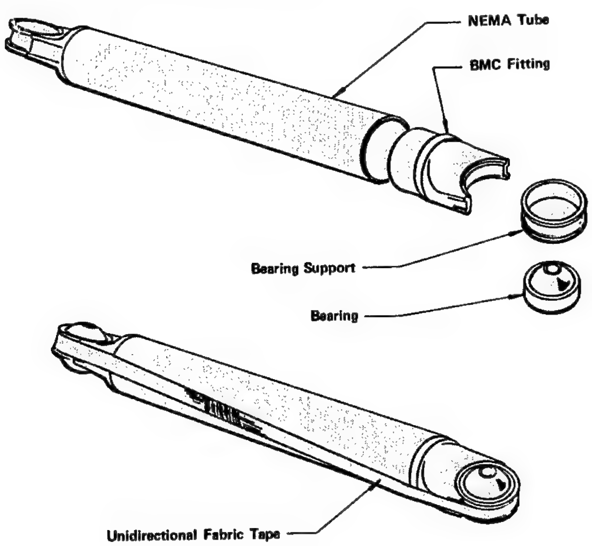


Figure 1

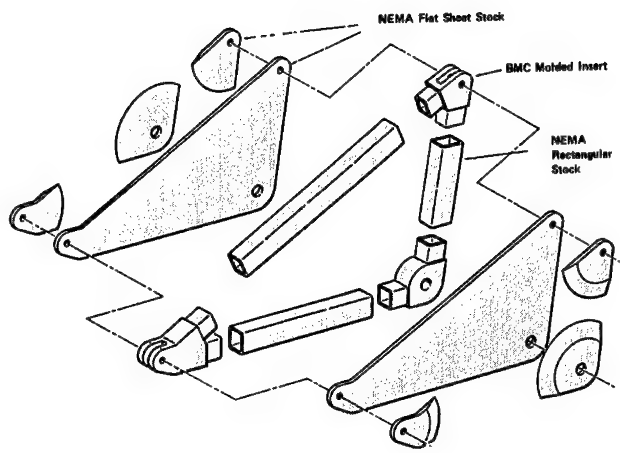


Figure 2

The manufacturing process developed entails four primary tasks:

- Molding of the fittings or details for each component
- Cutting of the NEMA grade tubular and sheet stock
- Assembly of each of the details for each component into the assembly fixture and subsequent bonding
- Installation and bonding of the bearing inserts, bearings, and bushings into each of the components.

Fewer Steps; In-Process Inspection

This manufacturing plan proved extremely cost effective and highly reliable. The major advantage was the small amount of processing—only the epoxy bulk molding compund required any in-house processing. Another important advantage was that the assembly fixture provides an in-process method of inspecting each detail of each component before installation into the final assembly and of inspecting the final cured and assembled component.

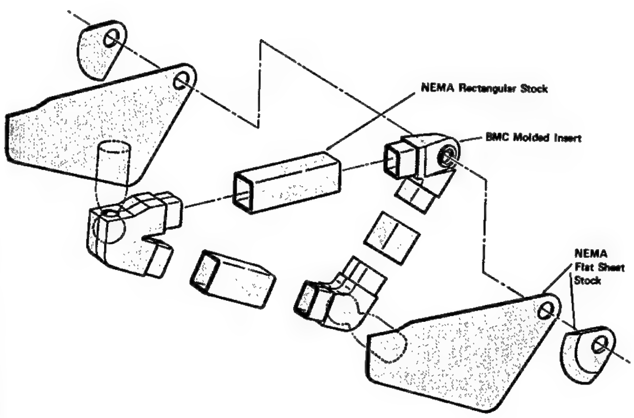


Figure 3

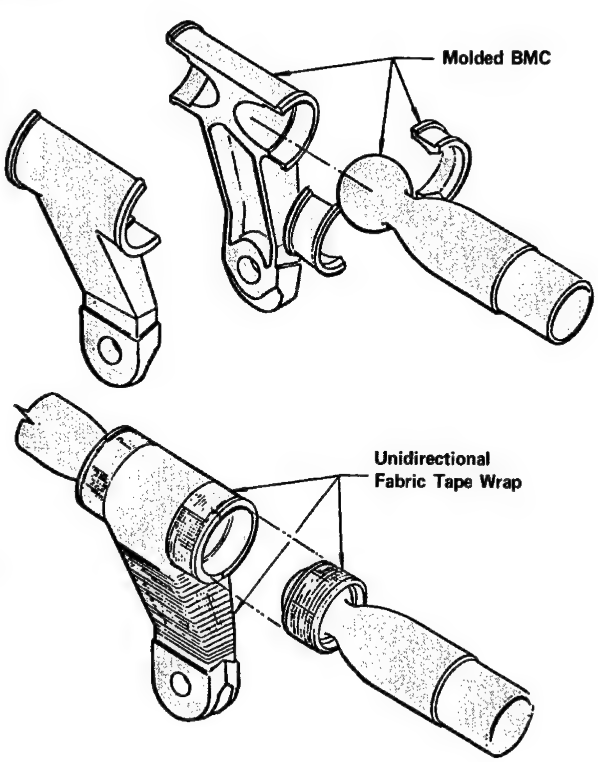


Figure 4

The process utilizes matched die precision molding and a final fixture that combines assembly with curing. Eleven matched metal dies were required to mold the complex details from BMC material. It was possible to mold six of the parts to final configuration. The other five required additional drilling after curing. Final assembly fixtures for each of the components held each detail in the proper position for bonding and provided clamping pressure during curing. The fixtures would not accept parts that were not dimensionally accurate, thus inspection capability was provided.

The techniques developed in this program make maximum use of commercially available finished material forms that require a minimum of additional processing. The matched die molding process allows rapid fabrication.

Completed components were tested for fit and function, mechanical properties, environmental exposure, and ballistic impact tolerance. The results of these tests established that the performance of each of the composite components is more than adequate for the operational loads that will be encountered.

UH-1 Components Also Investigated

Whittaker also developed techniques for manufacturing a connecting link and a quadrant assembly for the UH-1 helicopter employing ballistic damage tolerance in both design and materials. Again, the emphasis was on matched die precision molding and on a fixture that allowed combined final assembly and curing. Improved highly reliable methods were demonstrated with the resulting parts performing well in mechanical, environmental, and ballistic testing.

Bellcrank Costs, Weight Reduced

In another program, USAAMRDL developed manufacturing methods for a ballistic damage tolerant tubular/sandwich bellcrank for the CH-47. In this case, manufacturing costs were reduced by about 50 percent compared with metallic components. In addition, the

bellcrank weight was reduced from 3.4 to 1.65 pounds. Tests showed that the fiberglass bellcranks would operate satisfactorily at temperatures from -65 to 180 F after sustaining a fully tumbled .30 caliber impact. Furthermore, no flashing occurred on ballistic impact, as with metallic bellcranks, greatly reducing the risk of in-flight fire.

The fiberglass bellcrank is illustrated in Figure 5. The face sheets were made in pairs using matched metal molds. Three plies of prepreg 181 cloth, cut to size, were placed in the molds to form the stepped doublers for the attachment and point bearing areas. Four additional plies of 181 cloth completed the face sheet. On all surfaces to be bonded, fiberglass peel ply was used. Curing was done in a press at 325 F for three hours with a post cure at 350 F for one hour. A diamond bandsaw was used to cut the slots in the exit face.

The tubular elements were wound with six plies of 181 cloth on a square mandrel, again using peel ply for bonding surfaces. After curing in a press, the mandrels were removed, the angles on each tube were cut to final dimensions, and slots to accept the end attachments were cut.

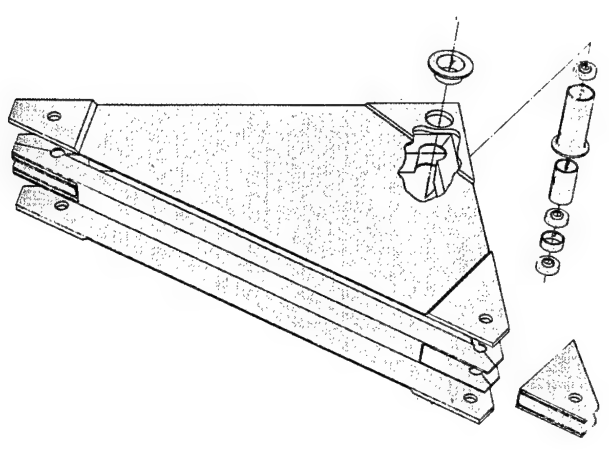


Figure 5

End attachments were fabricated in pairs in matched metal molds. Output attachments were four plies thick and input attachments were twelve plies thick. Integrally fabricated eight ply triangular shaped doublers served to align the tubular elements during final assembly and to provide additional stiffening and bond areas for the face sheet.

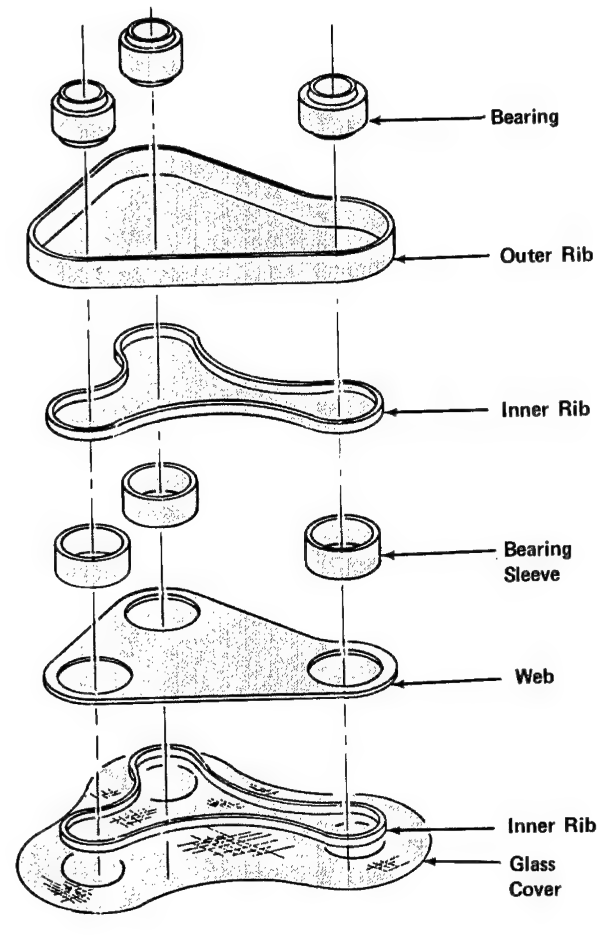


Figure 6

Final assembly of the bellcrank, including sleeve bearings and a pivot bearing, was done in a precision positioning jig. Bonding was with FM-1000 adhesive cured at 350 F in a hydraulic press at 50 psi. A high speed router was used for trimming to final dimensions. The bearings were fit in place after curing.

Bell Helicopter investigated manufacturing techniques for the bellcrank and a clevis for the AH-1G anti-torque flight control system. The parts first were redesigned for ballistic tolerance and then fabricated with specially designed tooling.

The bellcrank assembly is shown in Figure 6. The web is made of laminated prepreg fiberglass cloth. The inner and outer bands and the bearing sleeve are wound unidirectional fiberglass. A fiberglass overlay is used to reinforce the bands to the web. The webs, bands, and bearing sleeves were fabricated separately from prepreg materials and then assembled in a cavity bond fixture and cured in a platen press under heat and pressure. Ballistically tolerant bearings with a chopped graphite/epoxy molding compound inner race and glass fiber filament wound outer race were used at the pivot point and push-pull tube attach points.

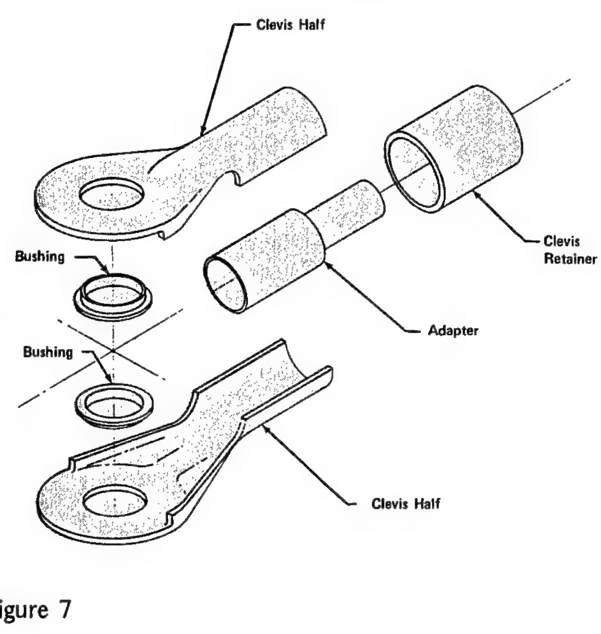
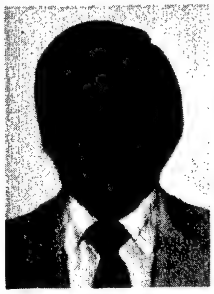


Figure 7

The Bell developed clevis assembly is shown in Figure 7. This part was made from fiberglass cloth. Fabrication consisted of preparing the two symmetrical clevis halves and two aluminum bushings and mating them with an aluminum adapter. Joining was done in a cavity bond fixture, which was placed in a platen press for curing at elevated temperature. After curing, a reinforcing wrap of prepreg filament yarn was applied using a filament winding machine. The reinforcement then was wrapped with heat treatable nylon film and the resin was cured in an oven.

Parts fabricated using the techniques developed during this program successfully completed mechanical, ballistic, and environmental tests. Residual static strength was sufficient to allow control of a helicopter after damage from a .30 caliber bullet. One drawback in this effort was the weight of the composite bellcrank—nearly twice that of the metallic part (0.74 vs. 1.44 pounds). Furthermore, the projected cost was considerably higher.

Overall, the USAAMRDL program has indicated the feasibility of fabricating ballistic damage tolerant fiberglass flight control parts on a production basis using low cost techniques. As a result of this effort, such systems are being given strong consideration for incorporation in the next generation of Army helicopters.



JAMES D. RAY is Manager of Composite Programs at Sikorsky Aircraft. He joined Sikorsky in 1976 as Manager of Structures and Materials. Since that time Mr. Ray has held several responsible positions, including that of Manager, Subsystems Design and Development, responsible for airframe rotor systems, transmission, and propulsion systems design. With the continued escalation of application of composite materials at Sikorsky, Mr. Ray was promoted to the position of Manager of Composite Programs reporting to the Director of Engineering. Before joining Sikorsky, Mr. Ray was with the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson AFB for eleven years. His responsibilities ranged from the characterization and composite development for the Air Force of the first graphite fibers available in this country to directing of the Air Force Advanced Development Program. Mr. Ray is a member of the American Helicopter Society, AIAA, AAAA, and SAMPE. He has authored, coauthored, and presented approximately sixty papers on polymer synthesis, fiber materials, composite materials, manufacturing methods and structures.

Composites Important to Black Hawk

Costs, Weight Reduced

When the Sikorsky UH-60A BLACK HAWK helicopter was first introduced, it had to meet some very stringent Army requirements for performance, weight, reliability, and maintainability. Thanks in no small part to the use of high strength composite materials, these requirements were met—often surpassed. The current BLACK HAWK model contains more than 551 pounds of advanced composite materials. Chances are good that this amount will increase with continuing manufacturing technology programs.

It wasn't enough just to meet performance requirements, however. Production costs were equally important. Composite components had a lot to offer, but only if they were cost competitive with their conventional counterparts. In many cases, Sikorsky had to develop new fabrication methods to accomplish this.

Sikorsky efforts in this direction have been very effective—costs often have been reduced. For example, evolution from the metal canopies of the early 1960's to today's molded fiberglass canopy has resulted in a steady decrease in fabrication man-hours. The innovative construction techniques used on the BLACK HAWK canopy require only about one third the man-hours used on those metal canopies.

The same techniques are now being developed for the BLACK HAWK rear fuselage, with manufacturing cost reduction of about 35 percent anticipated.

In addition to performance improvements and cost savings, manufacturing technology efforts have resulted in important new fabrication techniques that should enhance and extend the use of composites for other products.

Figure 1 shows the wide range of composite applications in today's UH-60A. Some of the components for which new manufacturing technology has been and is being developed are discussed below.

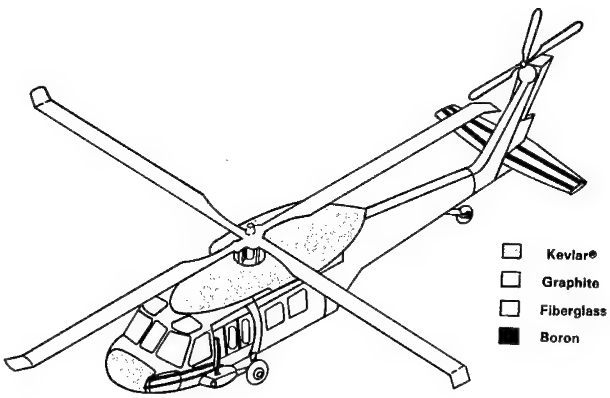


Figure 1

Blade Airfoil Critical to Performance

Improved rotor blade design along with new fabrication techniques have resulted from new uses of composite materials. The new family of rotor blades developed at Sikorsky utilizes a titanium spar with a fiberglass/epoxy structural fairing, which gives the blade its airfoil shape and edgewise rigidity. The airfoil shape is molded in place around the spar, making very complicated airfoil contours, thickness variations, and twist distributions possible. Because all blades are molded in the same tool, the blade to blade uniformity necessary for smooth flight is assured.

Although the heart of the BLACK HAWK main rotor blade is a plasma arc welded, hot formed titanium spar, composites are used extensively to increase its strength and durability and to reduce its weight. Composite components comprise approximately one third of the blade's weight. They include a fiberglass skin, a Nomex honeycomb core (shown being assembled in Figure 2), and graphite root end laminates.

The laminates are doublers that are bonded to the blade root end. They provide the predominant structural load path for the bolted attachment of the blade to the cuff. Testing at Sikorsky has shown that such bolted graphite composite joints are much lighter than similar

Figure 2

metal joints and have readily predictable static and fatigue strengths.

The high fatigue strain capability of composites allows the rotor blades to operate at high forward speeds and perform maneuvers that would cause damaging fatigue stresses in an all metal blade. This capability is even better utilized in the tail rotor spar.

Tail Rotor A True Composite

The cross beam tail rotor uses a true composite blade. The blade's airfoil section is constructed of fiberglass and graphite/epoxy bonded to a honeycomb substructure. The spar is pure graphite/epoxy, with the fibers oriented along the axis of centrifugal force.

This fiber orientation provides great strength in the direction of the centrifugal force. Yet the part is lightweight and—of greater importance—is pliable enough in torsion so that pitch changes of the blade are accomplished by allowing the spar to twist. This twisting

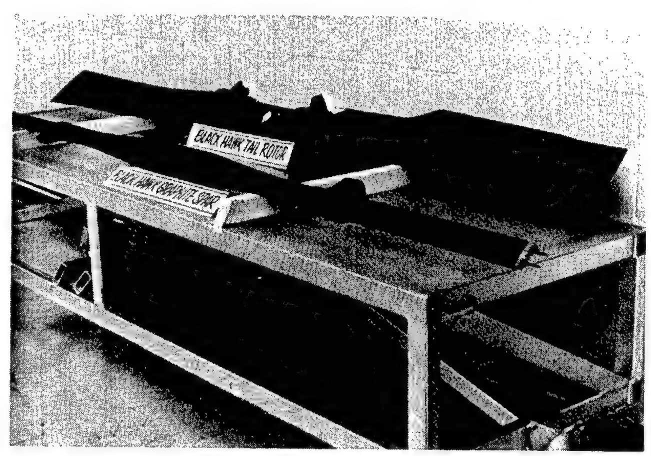


Figure 3

capability eliminates the need for pitch bearings and their related maintenance, cost, and weight penalties.

The spar is shaped to minimize flatwise stiffness, thus allowing the blade to "flap". This bending of the spar eliminates the need for a flapping bearing just as twisting eliminates the need for pitch bearings.

All of this results in a lightweight, articulated rotor without bearings whose hinges have no moving parts and require no maintenance.

The nearly 11 foot long tail rotor spar shown in Figure 3 is press molded. It has six separate regions where the cross sectional area tapers by more than five to one with a twist of 20 degrees. With a thickness tolerance of ±0.010 inch, it requires rigorous ultrasonic and shear strength inspections.

The tail rotor blade skin is also a complex twisted shape, whose thickness varies from 0.022 to 0.20 inch; it is made from a hybrid of fiberglass and graphite composites. The blade skin is molded over a mandrel in an autoclave and a deicing boot is bonded to it. Two skin assemblies are mated simultaneously to a single spar assembly and two aluminum horn fittings. A single operation bonds the low density honeycomb to the trailing edge of the spar and completes numerous rigid bond joints. Bonding pressure is obtained by autoclave, mechanical, and expanding silicone methods.

Sikorsky is continuing to evaluate potential new rotor system composite applications. Possible future uses for composites include the rotor head and a fully composite main rotor blade.

Airframe Weight, Parts Count Reduced

Helicopter airframes traditionally have used fiberglass reinforced plastics for secondary structures such as cockpit enclosures, main rotor pylon fairings, and doors. On the BLACK HAWK, adaptation of composite materials to new applications has resulted in weight savings and fewer parts. This expanded use also has brought improved methods for cutting and drilling Kevlar—a strong, lightweight (but difficult to machine) material.

One of the new applications for composites was the cargo floor, which generally has been in the form of metal honeycomb sandwich panels. In service, these panels can be dented or punctured. The BLACK HAWK uses all composite floor panels which result in a tenfold improvement in durability. The new panels are made from a cross plied, unidirectional fiberglass facing on a nonmetallic Nomex honeycomb core. Besides improving durability, the design—in which doublers and edge members are molded as integral parts of the skins—significantly reduces the number of parts.

In another change, boron/epoxy reinforcing straps were added to the cockpit support beams and stabilizer spars. Dynamic considerations demanded that both of these members be very stiff. Boron/epoxy was selected as the reinforcing material because of its superior stiffness to weight properties and because it was galvanically compatible with the standard aluminum fasteners used to assemble the structure.

New Cutting Technique Necessary

Use of this material introduced another problem, however. Boron is very hard and cannot be drilled with conventional metal cutting tools. Special procedures were needed. The one adopted uses diamond coated, hollow core drills that oscillate at ultrasonic frequency. With this equipment, holes can be drilled in less than a minute—a time that is compatible with conventional assembly techniques. Thus, the use of heavy steel or forged aluminum reinforcements was avoided.

The BLACK HAWK also includes about 50 Kevlar/epoxy parts that would have traditionally been made of fiberglass. Kevlar is a synthetic aramid fiber manufactured by DuPont that is 28 percent lighter than fiberglass and has very high tensile strength.

But, the use of Kevlar also presented certain problems. Kevlar is used in woven fabric form similar to its fiberglass predecessor; however, it has some very different characteristics that affect its producibility. Kevlar is inherently difficult to cut and drill, with a tendency to "fuzz" along any machined edge. An extensive program to solve this problem resulted in the development of a

whole new family of cutting tools and systems. Some of these changes were accomplished by simple modifications of tool geometry and shape. In other cases, new procedures, such as laser cutting and net molding techniques, were implemented. The end result is an important advance in production technology for this useful material.

Canopy Costs Reduced

Sikorsky pioneered the application of composites to cockpit enclosures with the CH-53 helicopter in 1963. This technology has now evolved to an extremely low cost fabrication method called "skin skeleton construction".

The original 1963 CH-53 canopies merely substituted fiberglass for metal. Individual framing members were molded from fiberglass instead of aluminum and then bonded into fiberglass skins. This initially conservative approach to composite fabrication was necessary to minimize development risks, but the design yielded only nominal cost savings.

Co-Curing A Milestone

The next milestone in production technology occurred in 1970 when the CH-53 canopy was redesigned to permit co-curing instead of bonding. Precast foam inserts were used to maintain the shape of framing members during cure operations. This design integrated many parts, resulting in significant cost savings.

Because of these CH-53 successes, fiberglass was considered a prime candidate for the BLACK HAWK canopy structure. Additional improvements were sought, however, by designing the structure as a molding to fully exploit the inherent producibility advantages of fiberglass.

Structural elements in the CH-53 were formed by foam inserts. This procedure had two disadvantages from a production viewpoint. First, the foam cores had to be precast—they were actually separate parts. Second, foam inserts were not stable and tended to shift or deform during autoclave curing. Thus, dimensions were not totally repeatable and considerable fitting was required during final assembly.

Skin Skeleton Concept Developed

For the BLACK HAWK, the totally new skin skeleton construction concept was developed. In this approach, the skin is molded as a single unit into which a matching one piece skeleton is bonded. The skin molding incorporates ply buildups and joggles that allow duplication of all of the window rebates, doublers, and minor equipment supports fabricated separately in a conventional structure. The skeleton also is a molding, which integrates frames, posts, and sills into a single piece. A completed canopy assembly is shown in Figure 4.

Tooling for this construction started with a master mockup of the nose section. From this mockup, two female molds were cast. One of the molds simulates the outside contour and is used as a skin mold. The other mold—representing the inside contour of the skin—includes mandrels for shaping structural members. Removable mandrels are used in certain areas to facilitate part removal.

Precise, Complex Contours

During development of the prototype YUH-60A canopy, there was a great deal of concern over the requirement of nesting the two highly curved, complex

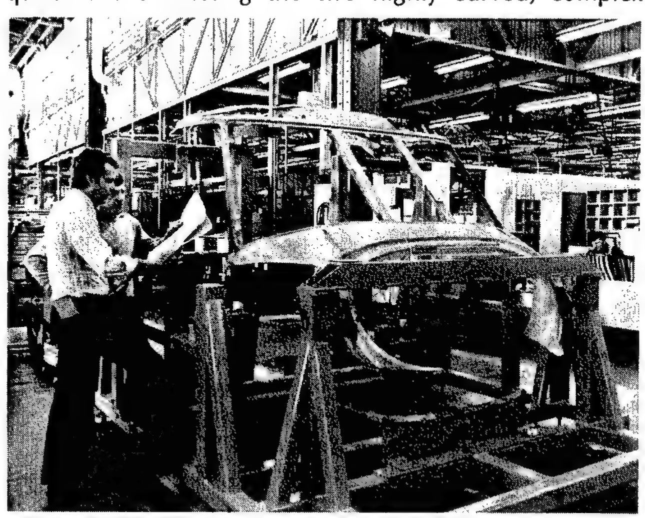


Figure 4

parts. Near perfect congruence was mandatory, since bond line thicknesses had to be controlled within precise limits. However, such fears proved groundless when good fit and excellent contour fidelity were achieved the first time.

This new design and fabrication concept sharply reduces production time. Figure 5 shows normalized manufacturing hours for the BLACK HAWK canopy compared with those for two other fiberglass canopies and a conventional sheetmetal H-3 canopy. The cost savings with skin skeleton construction are self evident.

35% Savings for Rear Fuselage

Engineering studies have shown that the proven skin skeleton construction can also be applied to the BLACK HAWK rear fuselage. This is a primary structure with compound curvature and very few systems interface constraints. The compound curvature means that virtually all of the 872 constituent parts must now be cut to shape, formed, and heat treated. Approximately 13,000 rivets are used to assemble the structure. Molded skin skeleton construction could dramatically reduce the number of parts and assembly operations, as shown in Figure 6. Industrial engineering analyses of this approach indicate a 35 percent reduction in unit cost.

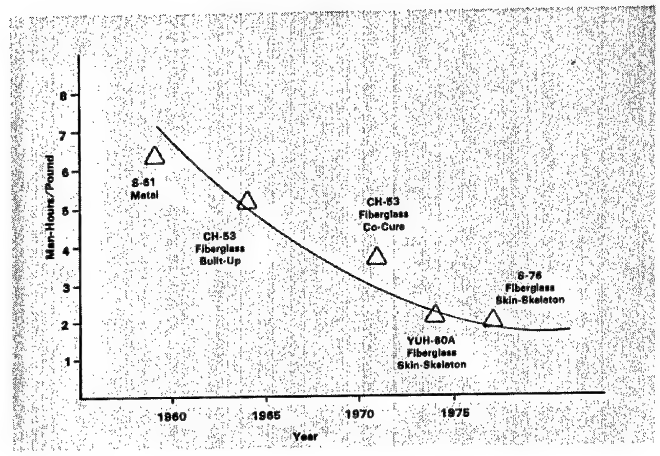


Figure 5

The predominant skin and frame material for the proposed structure would be Kevlar/epoxy. Stringers and frame caps primarily would be unidirectional graphite/epoxy. Use of these high strength materials should provide a weight savings of at least 10 percent.

Studies of potential improved fabrication techniques for the BLACK HAWK rear fuselage represent a major step in the continued evaluation of composite use in helicopter structures and establishment of methods to reduce manufacturing costs. These studies also will provide a basis for possible widespread application of composites in primary fuselage structures.

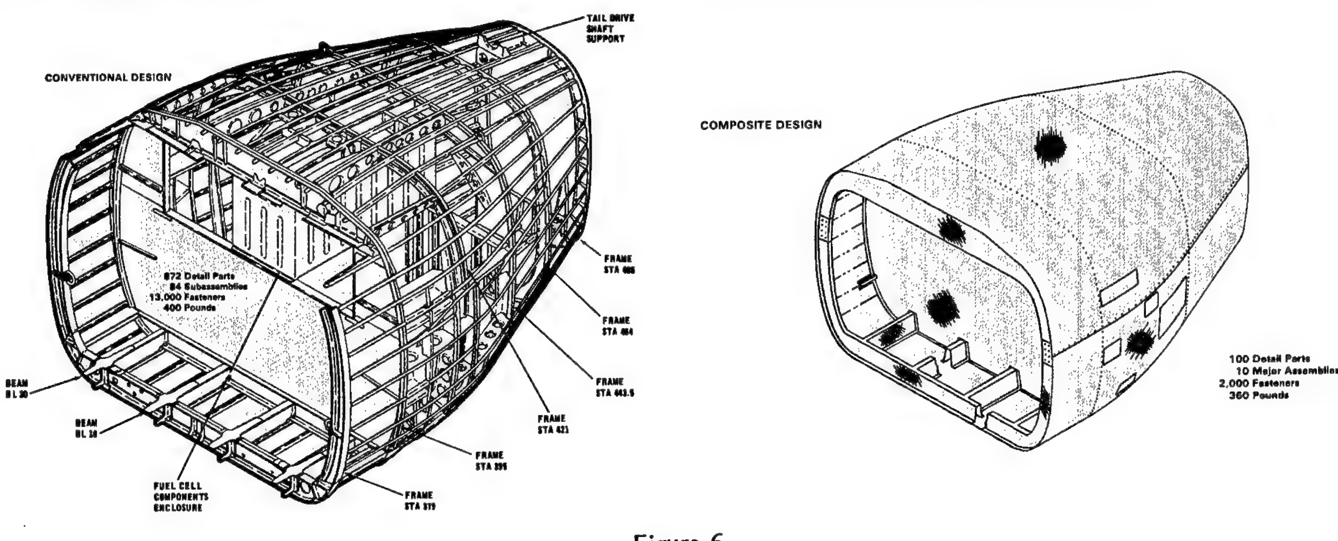


Figure 6

Practical, Quantitative Data

A Helping Hand(book)

Army contractors (or any manufacturers, for that matter) facing design and engineering problems may find ready assistance through the Army's Engineering Design Handbook series produced by the U.S. Army Materiel Development and Readiness Command (DARCOM). This coordinated series of handbooks provides basic information and fundamental data essential in the design of Army materiel and systems. While directed specifically at Army systems, much of the information has much broader, more general applications; most of these handbooks are available to the general public.

The handbooks cover a wide variety of topics. Many deal with specific materiel categories—weapons systems, infrared systems, servomechanisms, automotive systems, fuzes, and propellants, for example. Others cover more general topics such as producibility, value engineering, experimental statistics, environmental engineering, reliability, systems analysis, computer aided design, packaging, and maintainability.

The engineer using these handbooks will find practical information and quantitative facts that will help in materiel design and development. The books incorporate sound, proven design principles and contain much information not available in the open literature. Periodic revisions insure that the series keeps pace with the Army's rapidly advancing manufacturing technology.

A summation of DARCOM's intentions in initiating and maintaining the series highlights the utility of these handbooks. The series is intended to

- Conserve time, materials, and funds by outlining approaches to engineering problems that are most likely to produce results.
- Provide a reference of fundamental design information not readily available elsewhere—in a form that will facilitate the evolution of new designs.
- Generate, compile, and maintain an up to date set of formulas, tables, and data critical to the design of Army materiel.
- Preserve a record of Army design experience, forestalling duplication of past experience and work.
- Preserve unique technical knowledge that otherwise would be lost when experienced design engineers resign, retire, or expire.
- Provide orientation and guidance for new personnel and for Army contractors.
- Communicate to design engineers the requirements and disciplines of the allied technical fields with which they are concerned.
- Permit design of Army materiel to proceed at an accelerated rate—particularly under conditions of mobilization or other emergency, when experienced designers are overtaxed with urgent requirements.

The handbooks are aimed primarily at

- Army design engineers with many years of experience
- Recently graduated engineers with limited knowledge of the principles of Army design
- Specialists in a particular field of Army design but with superficial knowledge of allied fields
- Design engineers employed by contractors.

However, these handbooks also have proven valuable as tools in the training of technicians and as reference volumes for those concerned with procurement, production, inspection, drawings and specifications, testing, maintenance, maintainability, and administration.

The preparation and production of each handbook is sponsored by the cognizant DARCOM agency. Research Triangle Institute has the primary responsibility for overall preparation through a contract with DARCOM. Most of the handbooks are written by subcontractors to RTI who have expertise in the particular area. Technical advice and guidance on each handbook is provided by an Ad Hoc Working Group of technically qualified persons chaired by an appointee of the sponsoring agency. With this system, the user can be sure of a high quality and technically accurate presentation.

Although a few of the handbooks are classified, most are available through the National Technical Information Service at prices ranging from $4.50 to $25.00. Classified handbooks are available to registered users with proper need to know through the Defense Documentation Center. A list of all handbooks currently available and in preparation, together with information on obtaining them, is available from the National Technical Information Service, Department of Commerce, Springfield, VA 22161.

Brief Status Reports

NOTE: All the Brief Status Reports in this section except one are Manufacturing projects sponsored by AVRADCOM.

Ultrasonically Assisted Forming Of Nose Caps For Rotor Blades. The purpose of this program is to develop production techniques for cold forming erosion-resistant nose caps for helicopter rotor blades. Currently, titanium nose caps for the CH -47 modernization, and UTTAS fiber glass rotor blades and stainless steel nose caps for the AAH are being hot formed. The hot forming processing requires long processing times, high -cost tooling and equipment, and expensive chemical etching. Based on results of prior IR&D efforts and demonstrated effects of ultrasonics on forming of other materials, ultrasonic energy will solve the problems associated with the cold forming process, such as force required, spring back, and cracking. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Four Inch Thick Cast Steel Armor. Controlled solidification makes it possible for Army researchers at the Army's Materials and Mechanics Research Center to cast armor plate four inches thick which has a ballistic capability equal to or higher than rolled plate. In a jointly funded program with industry (Blaw-Knox and Rockwell), AMMRC has successfully demonstrated the feasibility of casting armor—culminating seven years of development. The current MM&T Program, "Improved Large Armor Castings", is not scheduled for completion until 1981; however, implementation of this new manufacturing technology is planned for mid-1980 on the XM1 vehicle. For additional information, contact Mr. Victor M. Pagano, (313) 573-2433.

Engine Nozzle In-Process Inspection. The objective of this project is to develop nondestructive test techniques for examining assembled T-700 engine nozzles for flow blockage and determining air flow volume. Automatic electrical measurement devices will be developed, as well as holding fixtures to group nozzle segments as a full assembly. A prototype automatic flow area measuring device with digital display and printed readout has been developed. This project will speed the necessary area measurement and flow control checks, thereby reducing operational cost. The end products of the project will be nondestructive test equipment and test techniques developed for the solution of inspection and quality control problems associated with small, air-cooled, turbine nozzles. For additional information, contact Mr. Fred Reed, (314) 268-6476 or AUTOVON 698-6476.

High-Strength, Flexible Cargo Restraint Devices. Manufacturing technology and production standards for fabricating flexible cargo restraint devices will be developed. These devices, utilizing a high-strength and high-modulus organic fiber, are designed for use in helicopter slings. One of the major objectives of the project is to develop methods and weave configurations that take advantage of Kevlar's high longitudinal tensile strength and minimize the effect of Kevlar's poor transverse compressive strength on webbing permormance performance. Various weaves and webbing configurations have been tested in the laboratory at AMMRC. Additional laboratory and field testing will be conducted. For additional information, contact Mr. Dan Haugan (314) 268-6476 or AUTOVON 698-6476.

Isothermal Roll-Forging Of Compressor Blades. AVRADCOM is developing manufacturing technology for isothermal roll forging of precision compressor blades. The work is being performed at Solar. Roll forging will replace the conventional blade manufacturing process. Recently, the isothermal roll forging machine setup was modified for blade airfoil forging. An atmosphere enclosure on the machine prevents burnup of the graphite lubricant during forging. Surface contamination of AM-350 roll forgings by the graphite forging lubricant was studied. This study showed that forgings made in 15 seconds at temperature are contamination free except at the point of initial die contact, where high current densities and overtemperature resulted. Technology Laboratory, /t. Eustis, Va. is the principal investigator. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Surface Hardening of Gears, Bearings, and Seals. This project seeks to develop and demonstrate the use of lasers for heat treating and surface hardening bearing races (now through hardened), gear teeth (now case carburized), and seal runners (now ground and polished). This new heat treatment process will improve the impact strength and fracture toughness of the bearing races and reduce the manufacturing costs by requiring less energy, eliminating quenching dies and possibly eliminating finish grinding. During the course of the work, heat treating processes will be optimized and control parameters will be established. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Precision Forging Of Spiral Bevel Gears. An alternate method of spiral bevel gear fabrication for current and future aircraft systems was developed during this program. The parts were forged at TRW, Inc. and tested at Boeing Vertol. Forging is performed on a mechanical press. Two forging blows are struck in rapid succession with reheating, to obtain forgings with integrally forged tooth forms. The geometry of the as forged tooth forms is controlled so that the resulting machining stock envelope is suitable for carburizing and finish grinding. Evaluation of gears forged in this manner included deflection tests, rotating load tests, and surface-fatigue tests. The results of this testing indicated that the surface load capacity of the integrally forged gear sets is at least equivalent to that of the conventional baseline gears. For additional information, contact the principal investigator at AVRADCOM, Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

Evaluation Of Neutron Radiography For Quality Control Inspection. The purpose of this project was to develop the N-ray technique as a quality control tool in the manufacture of Army Aircraft components. Neutron radiography, photon scattering, and acoustical holographic techniques were evaluated on hot-isostatic pressed (HIP) parts of the T-700 engine. These tests were run at General Electric, IRT Corporation, and Holosonics, Inc., respectively. The results of the test evaluation show that: (a) FPI inspection can detect surface flaws, (b) standard ultrasonic inspections are unable to detect most flaws due to high noise characteristics of HIP processed Rene' 95, (c) neutron radiography is generally unable to detect flaws in Rene' 95, (d) photon scattering gauge techniques are effective; and (e) acoustical holography will detect flaws in samples as low as one mil in size at all levels of thickness. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Superplastic Forming Of Titanium For Helicopter Component. This project was the highest rated proposal received by the Airframe Panel at the Army Aviation ManTech Conference. Its primary objective is to establish a production base and verify process reproducibility for the superplastic forming/diffusion bonding (SPF/DB) process. This process will be applied to helicopter firewalls and engine access panels. Process variables will be firmed up and a production run to determine costs and reproducibility will be made. The project will reduce component fabrication and assembly costs, as well as the weight of the structure. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

Cast Titanium Compressor Impellers. Technology for fabricating titanium compressor impellers by casting and hot-isostatic pressing is being developed to replace the current method of machining impellers from forged billets. Mechanical properties of the cast material are improved by hot-isostatic pressing. Final machining is by either mechanical or chemical milling. The new method of fabrication will reduce production costs by 40 to 50 percent by substantially reducing billet waste and reducing machining costs. For additional information, contact Mr. Gerald Gorline, (314) 268-6476 or AUTOVON 698-6476.

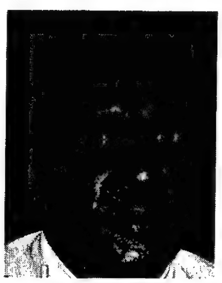
Production Methods For Multi-Element Antenna Modules. Use of phased-array antennas in airborne equipment has historically been rejected because of their high cost and excessive weight. A major cost contributer in a phased-array antenna is the necessary electronic components. This cost can be significantly reduced through integrating these components into sub-array modules. This project will develop methods and techniques to replace manual operations in the fabrication of modules with automated techniques. For additional information, contact Mr. Fredrick H. Reed, (314) 268-6476 or AUTOVON 298-6476.

Semi-Automated Composite Manufacturing System For Helicopter Fuselage Secondary Structures. A program to demonstrate a semi-automated manufacturing system for the production of helicopter secondary structural components made from composite materials is under way. The Grumman Aerospace Automated Composite Laminating System, developed for the Air Force, will be modified as required to accommodate selected AAH and/or Black Hawk composite secondary structures. Contractors for these helicopter systems will select their respective aircraft components for subsequent automated fabrication. Detailed structural characteristics/configuration, materials development and qualification testing will be performed by the AAH and/or Black Hawk contractors. Coordination meetings with the Air Force, Army, Grumman Aerospace, Hughes Helicopters, and Sikorsky Aircraft have been conducted. Grumman is conducting a fabrication cost analysis on input provided by Hughes. L. Thomas Mazza, Applied Technology Laboratory, Ft. Eustis, Va. is the principal investigator. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698-6476.

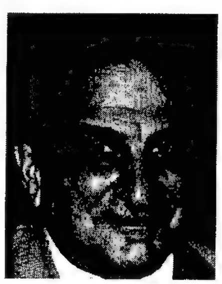
Non-Destructive Evaluation Techniques for Composite Structures. A manufacturing handbook on nondestructive in-process inspection of composite structures for helicopters is being compiled. Initial data will be developed for a composite rotor blade. Once the data are obtained, they will be applied to other composite structures. Depending on the configuration and stress levels in the structure, various criteria will be established for acceptance or rejection based on number, type, and size of the measured defects. The proposed handbook will list the types of structures inspected, the type of inspection methods to be used, the defects to be tested for, and the acceptance/rejection criteria to be applied. For additional information, contact Mr. Dan Haugan, (314) 268-6476 or AUTOVON 698 -6476.

Rapid Feedback of Production Information

Automated Ultrasonics Help Control Processes



CLARENCE J. CARTER is a Research Associate with the International Harvester Company, Manufacturing Services Division, Hinsdale, Illinois. He has been working as a Research Metallurgist at International Harvester since 1963, where he has been active in the areas of failure analysis and nondestructive and mechanical testing. Mr. Carter received his B.S. in Metallurgy and Chemistry from the Illinois Institute of Technology in 1956. From 1952 to 1963 he was employed as an Assistant Research Metallurgist at the Armor Research Foundation, Chicago, where he worked in the development of high temperature, high strength alloys. He is heavily experienced in work on titanium, ferrous and powder metallurgy, high vacuum techniques, and mechanical testing.



RAYMOND CELLITTI is Manager, Metallurgical Process Research, at the International Harvester Company, Manufacturing Research Division, Hinsdale, Illinois. He joined the company in 1947 as a Research Metallurgist after receiving his B.S. in Mathematics and Physics from Loyola University. He was instrumental in starting all applied mechanics experimental stress analysis techniques at International Harvester, besides applying fatigue analysis theories to product design and fatigue damage. He was promoted to management in 1955 after receiving his M.S. in Mathematics and Physics from Loyola University as Supervisor of the Applied Mechanics Laboratory, which included nondestructive testing. Appointed to Chief Research Metallurgist in 1963, he was in charge of Corporate Process Metallurgical Research, including heat treat engineering, foundry, and metal processing. He supervised metallurgical laboratories such as electron microscopy, fatigue testing, process control system development, and nondestructive testing. At the time of this appointment, he also was made Government Contract Administrator for Manufacturing Research.

Recent efforts at International Harvester in conjunction with the Army's Material Testing Technology program have produced automated testing and inspection systems that offer both immediate and long range cost and reliability benefits. The improved techniques have grown out of cooperative efforts fostered by an awareness of mutual technical needs. Among these new developments are techniques for automated ultrasonic inspection of materials for gun barrels, tank hulls and turrets, and torsion bar springs; impact testing of gun barrels; nondestructive

inspection of cast iron components; and preloading of threaded fasteners.

The benefits provided by these advanced techniques cover such areas as

- Reduced processing and inspection costs
- Energy and material conservation
- Greater product reliability
- Rapid feedback of information to control manufacturing processes
- More complete inspection coverage
- Elimination of human interpretive errors.

Some of the automated inspection systems that have been developed and are now in use or undergoing further development are described herein. With proper adaptation, these techniques should be applicable to materials testing in many types of manufacturing and should offer some of the same benefits listed above. Certainly, the usefulness of these systems is not confined to the limited number of military applications outlined here.

Automated Inspection of Billets Reduces Costs

One important development in automated inspection is that of computerized ultrasonic systems for detecting nonmetallic inclusions in semifinished bar and billet material. The U.S. Army Armament Command at Rock Island Arsenal, Rock Island Illinois, uses such a system for rating gun tube steel. A similar system has been installed at the U.S. Army Ammunition Depot at Shreveport, Louisiana, for measuring material quality of shell cases. These systems provide rapid inspection and their use minimizes those processing costs that result when finished parts are rejected due to material imperfections. The system should be useful in any industrial process where "cleanliness" (freedom from inclusions) of the material is an essential element in the quality of the final product.

The development and acquisition of a computerized ultrasonic inspection system was primarily motivated by the repeated occurrence of defects that are inherent in the steelmaking process. Many part defects were directly traceable to nonmetallic inclusions in critical areas—e.g., the journal fillet area of crankshafts and the inside bore of 20-mm gun tubes.

Thus, reliable inspection of billets was needed to catch these defects before costly manufacturing operations were performed. A cooperative program between Rock Island Arsenal and International Harvester paved the way for development of a computerized ultrasonic system for rating the quality of material in the semifinished condition.

Ultrasonic inspection coupled with high-speed data processing equipment provides a reliable quality control too! The technique is rapid and nondestructive and, with suitable instrumentation, eliminates interpretive judgment.

However, conventional ultrasonic methods for detecting inclusions are confined to scope displays that require manual handling of the data. The vast amounts of data that can be accrued in a relatively short time are difficult to assimilate and analyze manually. The automated ultrasonic inspection system overcomes this problem and provides reliable ascertainment of inclusions. In addition, the system assigns an ultrasonic signature number that is, or can be, related to mechanical properties, thus introducing a higher degree of design confidence.

The system's electronic instrumentation is designed to sample the ultrasonic analog at selected intervals, perform a continuous count of inclusions of various sizes, and mathematically process the counts to obtain a cleanliness rating for the material.

A flow diagram of the computerized system is shown in Figure 1. The billet or bar material is scanned at 8 inches/sec and an ultrasonic pulsing rate of 750 per second. Time varying pulses reflected from defects and nonmetallic inclusions are sampled, classified (by size) by the analog-to-digital converter, and stored in computer memory.

When the scan is completed, the computer automatically calculates a material cleanliness rating using stored weighting factors for different defect sizes. The data is displayed by teletype printer. The printout lists the number of counts obtained for each defect size classification, the ratio of various defect size counts to total count, and the cleanliness rating. The weighting factors can be arbitrarily selected or altered to exemplify the mechanical properties. A correlation of mechanical properties and ultrasonic size classification has been established for various materials and strength levels. The weighted cleanliness rating provides the quality assurance manager with a quantitative measure of material quality and predictable behavior.

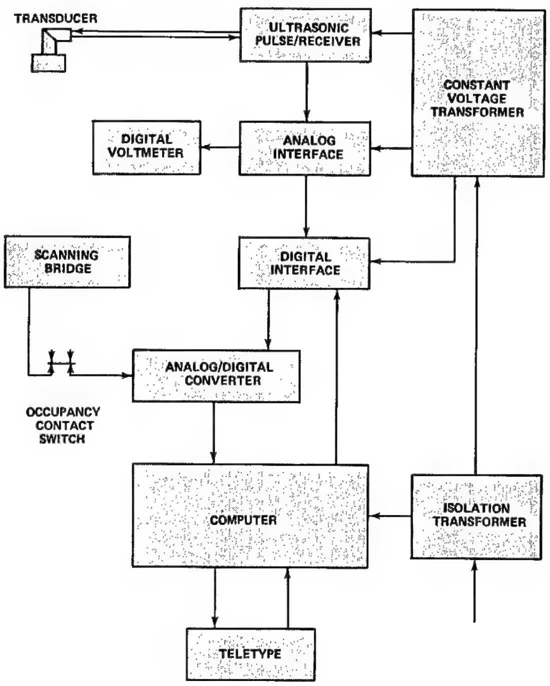


Figure 1

This tabulation shows the comparable level for the weighting factor and does not compare size. The relationship between ultrasonic category level and inclusion size was determined by light microscope analysis in which the incremental levels (0.001 in.) of samples previously rated by ultrasonics were examined. Inclusion areas were measured and compared with ultrasonic measurements. The relationship between ultrasonics and light microscope measurements is shown in Figure 2. Many of the parameters studied and resolved are now contained in Method B of ASTM E588.

n	AMS 2301, Lgth in In.	Ultrasonic Voltage	Weighting Factor
1	1/16 to 1/8	0 to 0.62	0.5
2	1/8 to 1/4	0.63 to 1.35	1
3	1/4 to 1/2	1.36 to 1.87	2
4	1/8 to 3/4	1.88 to 2.50	
16	Over 1-1/2	9.38 to 10.00	$2^{(n-2)}$

The ultrasonic inspection system provides information relating mechanical properties of billet and bar stock for various material cleanliness levels. As with other materials described above, it permits inspection and qualification of the heat before costly forging, heat treating, and machining operations are undertaken.

Ultrasonic Inspection of Torsion Bars

This automated ultrasonic inspection system also has been applied to inspection of torsion bar materials. The system allows complete volumetric inspection of both billet and bar stock from which torsion bars for the M-60 tank are initially processed. A special fixture connected to a variable drive motor rotates the round bar while the transducer scans the bar length.

While visual inspection of surface and near surface discontinuities in these materials may afford suitable control of large defects and discontinuities, small defects go undetected and provide crack initiation sources. These cracks may grow to critical size in service, causing the torsion spring to fracture.

Standardization of Test Results

As we have seen, the integration of ultrasonic flaw detection equipment with computers and other automated recording instruments has greatly enhanced the reliability of this nondestructive tool for quality control of semifinished material. However, a number of control setting parameters, individually and in combination, influence the overall inspection response of such systems. Some standardization of such parameters is needed.

An MTT program was initiated by the Army Materials and Mechanics Research Center to obtain and maintain uniform test procedures and to insure a high degree of reproducibility between various laboratories. Various ultrasonic test parameters such as specifications for search

unit performance, calibration procedures, automated counting methods, scanning patterns, and gated levels of sample inspection were investigated. Correlation studies to relate the ultrasonic severity rating (weighted for defect size) with aerospace magnetic particle inspection were conducted. The same weighting formula was used for both NDT methods; namely, 2n-2, where n is equivalent to the numerical order of defect size as shown below.

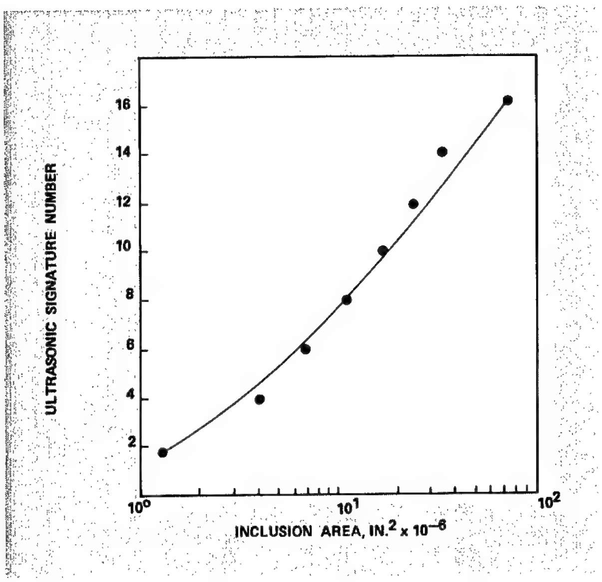


Figure 2

Automated Inspection of Tank Hulls and Turrets

Most inspection of the M60A1 tank hull and turret has been done by radiography. Radiographic methods, however, are time consuming and costly, offer limited resolution, and provide results that are hard to interpret. As a result, radiographic inspection of production castings is intentionally limited to avoid interfering with overall production schedules. Only critical areas are radiographed on every casting. Noncritical areas are randomly selected so that only 1 of 30 castings is inspected completely.

In order to extend inspection coverage while improving economy and reliability, an automated ultrasonic system that can inspect curved surfaces was designed. This system has been successfully demonstrated as a reliable inspection tool for both the front hull and turret. It is much faster and less costly than current radiographic techniques, insuring higher inspection coverage. And it can detect small defects that radiography misses, such as microporosity.

The higher inspection coverage, in contrast to radiography, does not interfere with production schedules. Remedial measures can be effected more quickly at the production site by the suppliers of tank castings to correct inadequate casting practices or to repair existing production castings to meet quality levels required by ballistic test criteria.

Transmission and reception of sound in the ultrasonic system is accomplished by a water coupling to the surface being inspected. This is done by a water squirter, which houses a transducer. For meaningful and accurate results, the transducer must maintain a constant water path length and constant angular relation to the surface. With the contoured and irregular surfaces of a turret, this requires continuous automatic adjustment.

Auto Positioning, Coupling Adjustment

Automatic positioning of the transducer for a normal (90 degree) inclination to the turret surface is controlled by a computer program. The first echo voltage is continuously monitored and its magnitude compared with a reference voltage stored in computer memory. When the computer senses a change between the reference and monitored voltage, it instructs stepping motors to move the transducer as required to correct the voltage reading.

The water path is also adjusted automatically by a reference voltage contained in computer memory. Electronic gates are utilized to bracket the first echo signal. When an inclined or curved surface alters the water path, the first echo signal shifts. This shift is encountered by one of the two gates. If the signal is shifted to Gate 1, the stepping motors that increase the length of the water path are automatically activated. If the signal occurs in Gate 2, the computer senses the voltage and activates controls to position the transducer closer to the surface. These adjustments

are made continuously so that water path length does not vary more than 1/8 inch. Adjustments are made in 1 to 5 milliseconds.

The results of ultrasonic readings correlate well with radiographic classification, as shown in Figure 3.

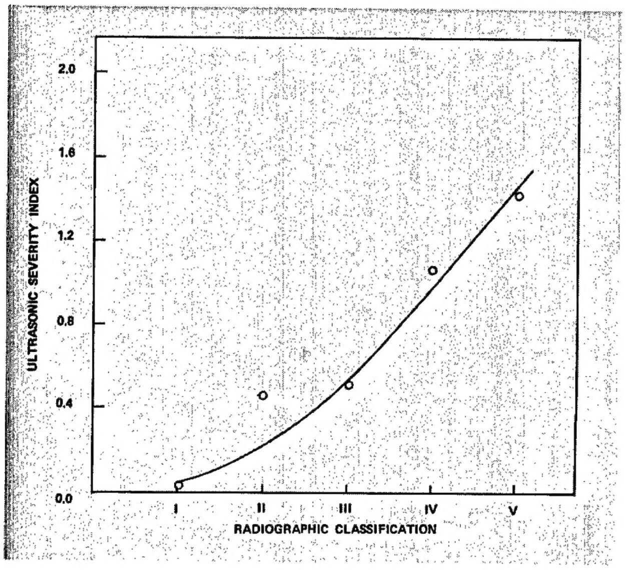


Figure 3

Impact Testing of Gun Barrels

Gun barrel materials are subject to repeated explosive shock and to rapid temperature changes caused by the friction of high-speed projectiles. Barrel life under these cyclic conditions depends on the size of internal flaws, such as cracks or nonmetallic inclusions, and on the rate at which these flaws grow to a critical size. The rate of crack growth varies with the ability of the material to resist crack propagation from the dynamic loads applied. This is measured by impact testing.

Automated test methods and instrumentation have been developed to provide greater impact test accuracy, higher testing frequency at lower costs, and standardized quality control test procedures for different thicknesses of gun barrel walls.

This computerized impact test system, currently installed at AMMRC, provides an economical, rapid, and reliable inspection system for controlling the quality of materials used in critical applications such as gun barrels. It utilizes the precracked Charpy V-notch bar with side notches to ensure sufficient constraint. This configuration provides an ideal specimen for several reasons. First, it is universally used and impact testers are widely available. Second, there is a solid base of testing experience. Third, specimen preparation is economical. Finally, it is a very rapid testing method.

The automated system uses sensitive instrumentation with rapid response capabilities. These instruments automatically delineate pertinent fracture information. Data on maximum load, time to fracture, impact energy, time to brittle fracture, crack initiation energy, crack propagation energy, and total fracture energy are printed automatically.

A schematic plan of this computerized impact test system is shown in Figure 4.

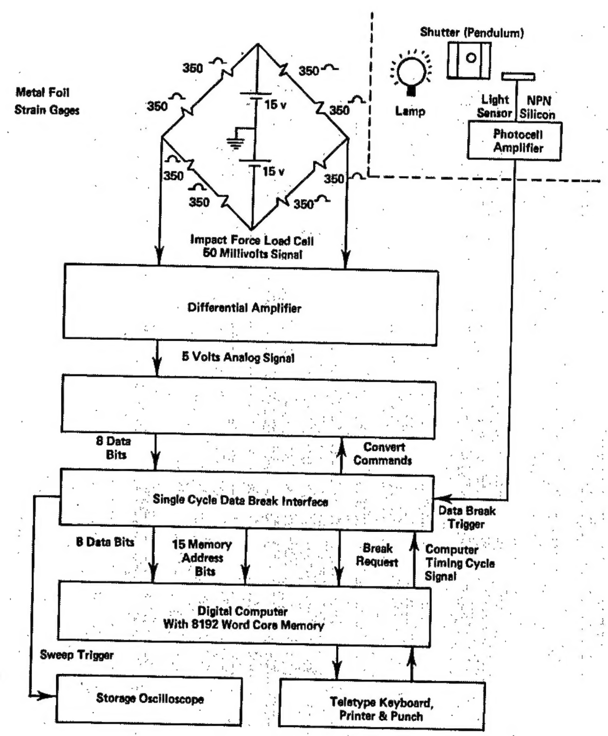


Figure 4

A photocell detector, mounted on the impact tester base, triggers the analog to digital converter. Millivolt signals are generated by strain gages (mounted on the top) during impact loading. These signals are amplified by the oscilloscope input vertical amplifier and transmitted to the analog to digital converter, which samples the amplified strain gage signals at 1.45 millisecond intervals. These signals are transferred through the interface module into digital computer memory at 690,000 conversions per second.

The computer senses the elastic oscillation cycle and time to fracture through programmed instructions and computes the pertinent area under the load time curve.

A more economical computerized impact test system which utilizes analog circuitry for data assimilation and processing subsequently has been designed, assembled, and installed at Watervliet Arsenal. This analog system offers automatic electronic analyses, a printout mode, and an oscilloscope presentation of load time data.

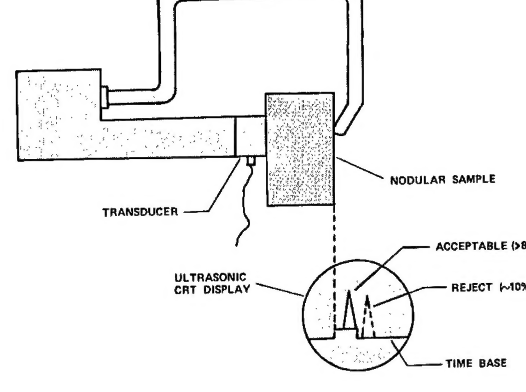


Figure 5

Specifications for Nodular Cast Iron

Complete nondestructive testing is required to evaluate the quality of nodular cast iron components. This ensures that optimum mechanical properties and metallurgical conditions are achieved. Test methods and specifications are available for radiographic, magnetic particle, and visual inspection. However, ultrasonic procedures and specifications related to the principal metallurgical constituent are needed to qualify the material as to degree of nodularity.

Such procedures can be based on the fact that the velocity of ultrasonic waves through ductile iron is a function of the percent of nodular graphite. During an MTT program at International Harvester, this knowledge was applied to provide a rapid and reliable method for qualifying the graphite morphology of recoil piston castings for the M158 gun mount. An integral part of this program was to establish standards and prepare specifications. In pursuing these ends, the ultrasound measurement program provided a means of quantitatively evaluating percent nodularity in production.

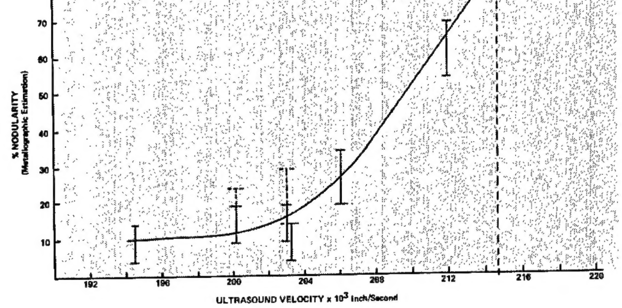


Figure 6

Both immersion and contact methods are applicable for ultrasonic velocity measurements in this regard. Figure 5 shows a commercially available contact unit. An immersion test unit (also commercially available) was used to correlate velocity measurements and percent nodularity, as subsequently examined and recorded by light microscope. This unit automatically corrects for part thickness and features a digital readout of ultrasound velocity. Figure 6 correlates ultrasound velocity and percent nodularity. A minimum ultrasound velocity of 214,500 in./sec corresponds to an acceptable nodularity rating of 85 percent.

As a result of this program, Watervliet Arsenal prepared a Military Specification (Inspection and Testing of Nodular Cast Iron) that subsequently was approved. That specification covers the chemistry range, mechanical properties, electronic equipment, sample conditon, test procedure, and sampling plan for continuous inspection acceptance.

Automated Control of Bolt Tension

A unique automated system for controlling bolt preload has also been designed and assembled. This system features an economical microcomputer which is coupled with sensing elements attached to an electronically controlled torque wrench for accurate production control or audit of bolt preload. Wide utilization of the system is envisioned at International Harvester and within the U.S. Army depot system as both a production and quality control tool for determining if bolt torque loads are within specified limits.

Proper preloading of threaded fasteners is essential to reliable component performance, particularly under cyclic loading. In current practice, preload and fastening tension of threaded fasteners is controlled by means of a torque wrench or by turn of the nut methods. The amount of torque available for effective tension in threaded fasteners is a very small percentage of the overall applied torque. Torque is largely dissipated by various frictional forces arising from bolt material, contact conditions in the threads and under the bolt head, and other manufacturing variables.

To ensure that the initial tension or bolt preload of a clamped assembly is greater than the maximum external load that will stretch or bend the bolt, a reliable automated system for maintaining and monitoring a specified preload is required. That system is now available.

Double Duty Tool

The system is useful either for production control or as an auditing tool. In production control, the system will automatically shut off an air wrench to verify if the preload is within specifications. As an auditing tool, it will discern if

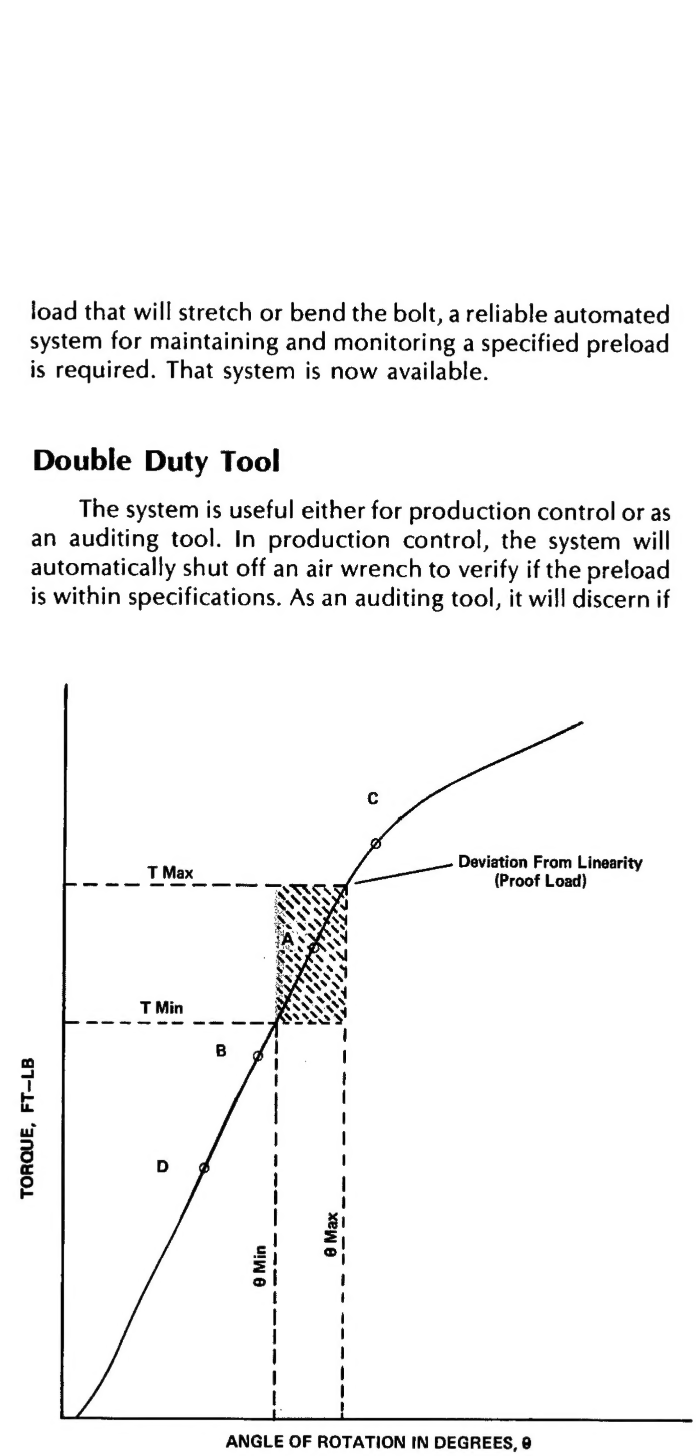


Figure 7

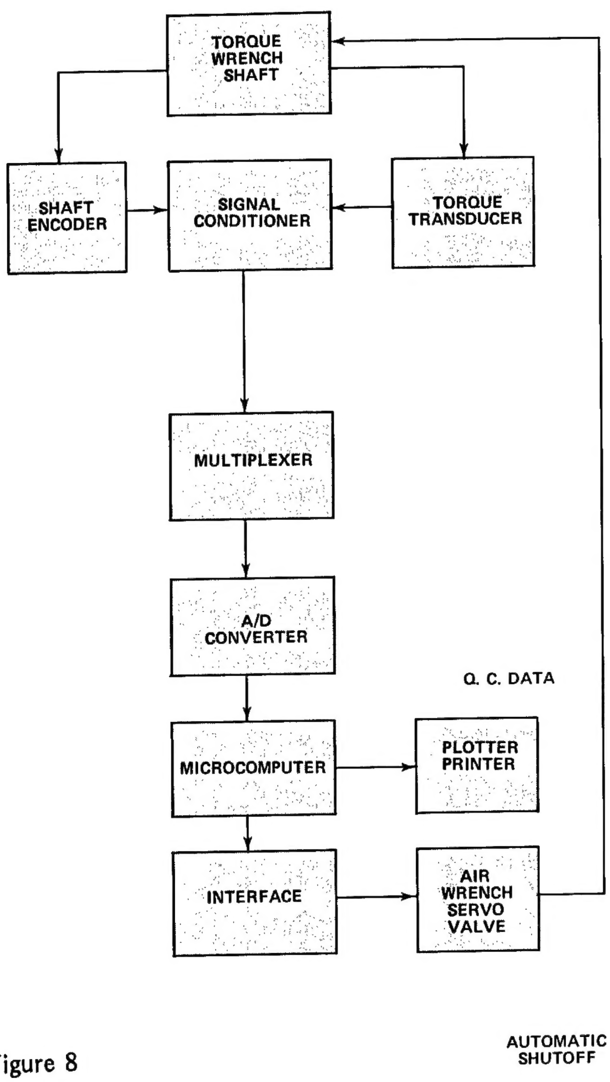


Figure 8

the preload is not within specification and make the required correction or adjustment. This is achieved by continually monitoring torque versus twist by computer assimilation and sensing the point where deviation from linearity, or bolt proof load, occurs. Figure 7 shows the linear relationship between torque and twist angle of a bolt during loading. A block diagram of the automated system is shown in Figure 8.

For **production control**, the bolt is tightened by an air wrench until proof load is reached. A shaft encoder attached to the air wrench drive spindle measures spindle angle displacement. The time factor associated with angle of displacement of the bolt is sensed, automatically stored, and printed out. The air wrench can be instructed to shut off automatically at any point on the curve in Figure 7. This feature provides a precision tool for use with production or assembly applications. In addition to an air compressor for activating the air wrench, the unit contains a battery to permit portable or field operations.

In the **quality audit mode**, the system measures the torque on bolts that have been previously tightened. The computer continuously monitors signals from the torque transducer and shaft encoder and compares these signals with specification limits stored in computer memory. The time factors associated with angular rotation are automatically compared with referenced time factors for various lubricated or coated bolts. Other changes in frictional force—such as cross threads, stripped threads, and contact conditions of the threads and mating surfaces under the head of the bolt—also will influence these time factors. If the time factors are not within specified ranges, the operator is alerted by a hard copy printout that the bolt should be replaced.

If the bolt is not properly preloaded, the computer calculates the required adjustment and transmits signals for automatic torquing of the bolt to the specified load.